JOINT ARMY-NAVY-OSRD CONFERENCE
ON PSYCHOLOGICAL PROBLEMS IN
MILITARY TRAINING

Proceedings. pt.1 Aug.15-16, 1945

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PROCEEDINGS OF PART I OF THE JOINT ARMY-NAVY-OSRD CONFERENCE ON PSYCHOLOGICAL PROBLEMS IN MILITARY TRAINING

August 15 and 16, 1945

Departmental Auditorium
Washington, D. C.

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John L. Kennedy

OSRD Report No. 6079
October 11, 1945

Applied Psychology Panel, NDRC

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Distribution List

Applied Psychology Panel

Executive Secretary, NDRC

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with NDRC

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Panel Liaison Officers

PREFACE

The experimental results and procedures reported at the Joint Army-Navy-OSRD Conference on Psychological Problems in Military Training represent only a small sample of the total contribution of professional psychologists in the Services and in the Office of Scientific Research and Development in attempting to speed up and improve the effectiveness of military training by the discovery and application of psychological principles.

At the request of the War Department Liaison Officer with the National Defense Research Committee and the Office of Research and Inventions, Navy Department, the emphasis of the present conference was placed upon the contributions of civilian psychologists working under the auspices of the National Defense Research Committee's Applied Psychology Panel. The plans for rapid demobilization of this organization during the terminal stages of the war made it appear timely to summarize the work in its military setting as rapidly as possible.

The program of the Conference was divided into four parts: I. On psychological problems in the design of military equipment; II. On training methods and devices; III. On selection and classification methods; and, IV. On methods of measuring the effectiveness of men's performance of military duty. The complete program of the Conference is reproduced on Page ii.

Certain specific requests were received by the Applied Psychology Panel for copies of the reports which were presented in Part I of the Conference. The reports of Part I, except for those of high classification, are reproduced herewith. The remaining reports of Part I and the reports of Parts II-IV are on file at the office of the Applied Psychology Panel.

Special acknowledgement should be made of the work of Major Howard E. Clements, Office of the War Department Liaison Officer with the National Defense Research Committee, Lt. Mary Wallace, Office of Research and Inventions, Navy Department, Dr. Walter V. Bingham, Chief Psychologist, Adjutant General's Office, War Department, and Dr. John L. Kennedy, Technical Aide, Applied Psychology Panel, NDRC, in the planning of the Conference.

Charles W. Bray, Chief
Applied Psychology Panel, NDRC

PROCEEDINGS OF JOINT ARMY-NAVY-OSRD CONFERENCE ON PSYCHOLOGICAL PROBLEMS IN MILITARY TRAINING

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5. TRAINING RADIO CODE OPERATORS. Dr. F. S. Keller, NDRC Project SC-88, Applied Psychology Panel

   COMMENT. Major P. C. Davis, Office of the Chief Signal Officer, War Department

6. VOICE COMMUNICATION (RADIO TELEPHONE AND INTERPHONE) TRAINING. Dr. J. W. Black, NDRC Project SC-67, Applied Psychology Panel

   COMMENT. Lt. J. C. Snidecor, Bureau of Naval Personnel, Navy Department

7. TRAINING ENGINEERING DIVISION PERSONNEL. Dr. B. J. Covner, NDRC Project NR-106, Applied Psychology Panel

   COMMENT. Lt. Comdr. H. H. Bailey, Large Ship Precommissioning Training Center, NTS, Newport, R. I.

8. TRAINING ARMY ANTIAIRCRAFT GUNNERY PERSONNEL. Dr. W. C. Biel, NDRC Project SOS-6, Applied Psychology Panel

   COMMENT. Lt. Col. H. R. Spaans, Antiaircraft Artillery Board, Fort Bliss, Texas

9. TRAINING SONAR OPERATORS AND OFFICERS. Dr. W. D. Neff, Columbia University, Division of War Research

   COMMENT. Comdr. R. D. Shepard, Office of the Commander-in-Chief, Navy Department

10. SUMMARY. Comdr. Lot Ensey, Bureau of Naval Personnel, Navy Department

PART III.

WHO SHOULD BE TRAINED? Some men learn faster than others. Some men learn any particular military specialty faster than others. Training has been speeded up and the final operating teams have been more efficient where each man is trained to do the job that he can do best; and is used in the job for which he has been trained.

Chairman: Brig. Gen. E. A. Regnier,
War Department Liaison Officer for NDRC

1. INTRODUCTION--PSYCHOLOGICAL PRINCIPLES IN MILITARY SELECTION, CLASSIFICATION, AND ASSIGNMENT. Mr. J. M. Stalnaker, Applied Psychology Panel, NDRC

2. PSYCHOLOGICAL TESTS AS PREDICTORS OF NAVY TRAINING SCHOOL PERFORMANCE. Lt. Comdr. G. L. Bond, Bureau of Naval Personnel, Navy Department

3. PSYCHOLOGICAL TESTS AS PREDICTORS OF ARMY TRAINING SCHOOL PERFORMANCE. Lt. Col. M. W. Richardson, Adjutant General's Office, War Department

   COMMENT. Dr. H. S. Conrad, NDRC Project N-106. Applied Psychology Panel

4. SELECTING RADIO CODE OPERATORS. Dr. G. K. Bennett, Applied Psychology Panel, NDRC

   COMMENT. Dr. E. R. Henry, Adjutant General's Office, War Department

5. ARMY CLASSIFICATION PROCEDURES. Lt. Col. E. K. Harrison, Adjutant General's Office, War Department

6. ENLISTED CLASSIFICATION PROCEDURES OF THE NAVY. Lt. Comdr. J. A. McCain, Bureau of Naval Personnel, Navy Department

7. EVALUATING OFFICER PERFORMANCE. Major R. M. Bellows, Adjutant General's Office, War Department

   COMMENT. Col. F. S. Foltz, Adjutant General's Office, War Department

8. STUDIES OF COMBAT CRITERIA IN THE ARMY AIR FORCES. Col. J. C. Flanagan, Office of the Air Surgeon, Army Air Forces

9. THE NOMINATING TECHNIQUE AND ITS OUTCOME. Comdr. J. G. Jenkins, Bureau of Medicine and Surgery, Navy Department

   COMMENT. Dr. W. V. Bingham, Adjutant General's Office, War Department

PART IV.

MEASURING THE EFFECTIVENESS OF TRAINING. As a continuous check on the quality of a training program and the effectiveness of selection and assignment, it is necessary to know how well men have been trained. School examinations and ratings of operational proficiency can be improved by fuller use of the knowledge of test theory and testing procedures.

1. INTRODUCTION--PSYCHOLOGICAL PRINCIPLES IN MILITARY QUALITY CONTROL. Dr. C. W. Bray, Applied Psychology Panel, NDRC

2. OPERATIONAL PERFORMANCE RATINGS. Dr. K. R. Smith, NDRC Project N-117, Applied Psychology Panel

   COMMENT. Lt. G. V. Lannholm, Bureau of Naval Personnel, Navy Department

3. EVALUATION OF MILITARY TRAINING BY MEANS OF PERFORMANCE TESTS. Dr. N. Frederiksen, NDRC Project N-106, Applied Psychology Panel

   COMMENT. Lt. S. H. Britt, Office of the Commander-in-Chief, Navy Department

4. MEASURING HEIGHTFINDER OPERATOR PROFICIENCY. Dr. W. J. Brogden, NDRC Project on Heightfinder Operators, Applied Psychology Panel

   COMMENT. Capt. H. E. Clements, War Department Liaison Office for NDRC, War Department

5. THE MEASUREMENT OF RADAR OPERATOR PROFICIENCY. Dr. D. B. Lindsley, Project SC-70, NS-146, Applied Psychology Panel, NDRC

   COMMENT. Capt. D. C. Beard, Office of the Commander-in-Chief, Navy Department

6. MEASURING PROFICIENCY IN ARMY SPECIALITIES. Capt. C. W. Taylor, Adjutant General's Office, War Department

   COMMENT. Lt. Comdr. R. N. Faulkner, Bureau of Naval Personnel, Navy Department

   COMMENT. Dr. W. V. Bingham, Adjutant General's Office, War Department

7. THE ORGANIZATION OF QUALITY CONTROL IN MILITARY TRAINING. Comdr. C. M. Louttit, Naval Training Center, Bainbridge, Maryland

8. SUMMARY. Col. L. O. Brown, Assistant Chief of Air Staff, Training, Army Air Forces

CONCLUSIONS AND OUTLOOK

1. CURRENT PROBLEMS OF MILITARY TRAINING. Major General I. H. Edwards, Assistant Chief of Staff, G-3, War Department

2. PSYCHOLOGICAL PROBLEMS IN POST-WAR TRAINING. Rear Admiral W. S. DeLany, Assistant Chief of Staff (Readiness), Office of the Commander-in-Chief, Navy Department

PROCEEDINGS OF PART I OF THE JOINT ARMY-NAVY-OSRD CONFERENCE ON PSYCHOLOGICAL PROBLEMS IN MILITARY TRAINING

INTRODUCTION TO THE CONFERENCE

by

Dr. W. S. Hunter
Chief, Applied Psychology Panel, NDRC

I was privileged to be one of a group aboard the USS MISSOURI on her structural firing cruise. The mechanical perfection of this ship filled all with profound admiration and confidence in her invincibility. But a battle-scarred admiral, when he spoke to some of us, referred not to the magnificance of the ship but to the human material that manned her. His words were: "2500 officers and men: Gentlemen, 2500 sources of error". That could be the text for this conference.

The holding of a joint Army-Navy-OSRD conference is symptomatic of a change in the conception of national defense from one which views national defense as solely the function of the armed services to one which seeks to safeguard national security by the total mobilization of the country's resources. When President Lincoln brought the National Academy of Sciences into existence, he recognized on a small scale the importance of civilian scientific aid in war. President Wilson asked the Academy to expand its activities by creating the National Research Council. He thus further developed the same idea in a world where science and engineering were more and more involved in the prosecution of war. It remained for President Roosevelt to bring this conception to its fullest development through the creation of the Office of Scientific Research and Development whereby large numbers of scientists with adequate laboratories and field resources could work in close liaison with the armed services in the rapid development of instrumentalities of war and their proper operation.

The OSRD is an agency of Government in the same sense that the Army and the Navy are agencies of Government. It is itself the greatest experiment conducted in the present war and one which I believe is destined to have most extensive consequences in the postwar world. Research in military science will proceed on a higher level during the coming period of peace than in previous postwar intervals. Civilian research of the broadest character and the development of scientific talent will proceed at an accelerated pace. The consequence will be the creation of a large reservoir of

knowledge and skilled personnel which will be available for the peacetime development of this country and for its defense in any future emergency.

Already the Secretaries of War and Navy have asked The National Academy of Sciences to establish a Research Board for National Security to be composed of an equal number of military and civilian personnel. The Board is to devote its talents to research development in the interests of national security viewed in its broadest sense. Dr. Bush has reported to President Truman on ways and means of continuing research at levels as high as or higher than those maintained in war. This report entitled "Science - The Endless Frontier" proposes that the government establish an independent agency to be known as The National Research Foundation. Its purpose would be to formulate national policy on scientific matters, to foster civilian and military research, and to discover and aid in the development of scientific talent. One may expect a certain amount of trial and error in the planning for postwar research before a settled policy is adopted. But that there will be an increased tempo in science with government support seems a foregone conclusion.

Military psychology is an American product. It began in the first World War under the direction of Major Robert M. Yerkes in The Surgeon General's Office and of Dr. Walter Dill Scott and Dr. Walter V. Bingham in The Office of the Adjutant General. Work at that time was concerned solely with the selection and classification of personnel by means of intelligence tests, trade tests, interviews and rating cards. Some experimental studies were made by other groups for the Air Forces, and some studies were made on gun-pointing for the Navy. But military psychology emerged at the close of the war essentially concerned with the selection and classification of general Army personnel. After the war Army psychologists returned to their civilian occupations, and both they and the Army went to sleep for 25 years so far as military psychology was concerned.

In view of the increasing danger of war, I interviewed the AGO in the spring of 1939 to see what help The National Research Council could offer in the field of psychology. I was shown the Army plans in this area which called for the use of the identical tests and procedures last used in 1918. I was assured that the situation was well in hand, and in turn I assured the AGO of the NRC's willingness and ability to help. I am happy to report that in the fall of 1939 the Army turned to NRC for help and advice with the result that an advisory committee was established under the chairmanship of Dr. W. V. Bingham. This group has had a distinguished career of usefulness ever since. There now followed rapidly the establishment of psychological services in the AGO, in the Army and Navy Air Forces,

The Bureau of Naval Personnel, the Morale Branch of the Division of Special Services, the Office of Strategic Services, and in a large variety of groups in various arms of the services, including medicine.

These strictly military activities were accompanied on the civilian side by the development of NDRC. Here psychological work started as early as 1941 in connection with under-water sound operators, fire control, acoustics and optics. In 1942 the NRC established a "Committee on Service Personnel - Selection and Training" supported by a contract with NDRC. This committee did so well that it was replaced in 1943 by the Applied Psychology Panel, an integral part of NDRC. The Panel was thus a late comer on the scene, and not all psychological work in OSRD has been under its supervision.

The program of the present conference makes no effort to report completely on the psychological work being done even by those groups represented. That picture is too extensive. Rather your attention will be invited to the specific problem of training and to the types of contributions which psychology has made to its solution.

Wars are not fought by machines, or by men alone, but by men operating machines. The man-machine is the unit. As hostilities progress, the engineers produce new machines of types often radically different from those available in the beginning. But no one has learned how to produce a new kind of man. War (and peace) must be waged with the human material available. Selection may be used to reject the unfit until the bottom of the manpower barrel is reached, and the fit can be classified for military jobs. But the nearest approach to the projection of new human material is through training which will fit the man to the job to be done.

It should be stressed that selection, classification, training and the design of new equipment are closely related procedures whose final test comes in combat operations. Men must be selected, classified and trained with reference to the characteristics of the equipment that is to be used. It is not so clearly recognized but it is just as true that the engineers must design equipment with a maximum regard for the human factor involved in its operation. This they have very often not done.

The details which will confirm these general statements of mine and make them concrete will be given by the men who follow on this program. I believe that military psychology has broken new ground in this war as it did in the last one and that its contribution to the problem of the role of the human factor in the design and operation of equipment will be recognized as perhaps the most important scientific instance of this. Whatever may be the scope of postwar military training and research in this country, it is certain that the problems of the human factor will demand adequate scientific consideration.

PSYCHOLOGICAL PRINCIPLES IN THE DESIGN AND OPERATION OF MILITARY EQUIPMENT

by

Leonard Carmichael
Applied Psychology Panel, NDRC

Psychology involves the scientific study of human behavior. The special techniques of psychology involve procedures by means of which human sensory processes and muscular responses are studied. This field also studies the neural or, as they are sometimes called, mental events which lie between the sensory and motor processes of the organism. Psychology is closely related to physiology and to neurology, but in the last half century it has developed many experimental techniques and a large body of factual knowledge bearing upon the effective operation of the human sensory-neuro-muscular mechanism.

In the design of many forms of military equipment it is important to consider, as the research and development antecedent to the development of a new model go forward, that the model shall not only perform the functions required of it from the military point of view but that it shall be adapted in the best possible way to the known sensory-neuro-muscular characteristics of the human operators who must use it.

Psychological experiments conducted upon preliminary models or upon laboratory simulations of proposed models often enable an optimum type of mechanism to be developed. Visual acuity, auditory acuity, tactual acuity, and muscular sensitivity are all important under certain circumstances. Psychological experimentation has demonstrated that acuities are a function of a complex series of variables, and often a slight modification of design makes the task required of the human operator much simpler than it could possibly be if various acuity factors were not taken into consideration. The human individual's ability to see a needle on a dial in a clear enough way to make accurate readings possible may be shown to be a function of (1) the length of time that the visual stimulus is acting on the retina; (2) the wave lengths of the light being reflected from the needle and scale; (3) the intensity of the light being reflected from the needle and scale; (4) the condition of adaptation of the eyes observing the needle and scale, including the immediately preceding visual task required of the eyes; (5) contrast between the needle, scale and background; (6) other visual stimuli simultaneously acting upon the retina; (7) the characteristics of the individual's eyes as corrected or not by lenses; (8) other non-visual stimuli simultaneously acting upon other sense fields;

(9) the muscular acts or actions required of the individual at the time the stimulus is being presented; (10) the emotional state of the individual; (11) the condition of the individual's blood in regard to oxygen and other components; (12) the fatigue and state of sleep deprivation of the individual; (13) the amount of training which the individual has had in reading such dials; (14) the general intelligence of the individual, at least in extreme deviations; (15) the distance away from the observer; and many other factors.

A similar series of factors could be described in connection with other senses. From this presentation it is clear that many visual tasks required in military work must involve a compromise, for example between an instrument panel so complex that its interpretation is slow and a panel that is so simple that it does not provide the necessary information. Thus in the development of special instrument panels, cathode ray tubes, and so forth, a study using modern psychological techniques under practical operational conditions is called for in order that the design settled upon may be as effective as possible for the largest number of potential operators.

On the motor side similar design problems present themselves. The appropriate use of coarse and fine adjustments in order to compromise speed and accuracy of setting involves the selection of the most effective gear ratios in devices which involve pip matching, tracking, or movements such as those required in azimuth and elevation settings of various sorts. Laboratory experiments in these fields conducted during the present war have shown surprising and constructive results concerning the desirability of certain gear ratios over other gear ratios, inertia, friction, direction of movement, hand used, and so forth.

Human posture is physiologically determined by a complex series of factors which include the central nervous system, the non-auditory part of the inner ear, and sensory endings in muscles, tendons, and joints. Eye movements, for example, are determined in relation to the total posture of the body as well as by stimulation of the retina. This means that in the design of various types of equipment the total postural set of the individual must be taken into consideration especially if the operation of the equipment requires sudden shifts in posture.

Studies conducted during this war indicate that a very long training period is often required in order to bring new operators to high levels of proficiency even in comparatively simple tasks. This fact indicates that in developing apparatus every effort should be made to design the equipment in such a way that its operation may be learned most quickly and so that the habits learned may persist during periods of lay-off.

The determination of which of two or more proposed procedures can be learned most readily can be made accurately only after careful technical psychological experimentation. It is also true that in the design of all such equipment appropriate techniques for the selection of individuals who show the greatest aptitude to learn the task quickly and to a high level of performance should be selected. Such selective procedures very often have to be developed in connection with specific new pieces of equipment. There is no place in which the difference between physics and psychology is more clear than in this very field. For example, a new piece of equipment might be under consideration which would require the operator to have good visual acuity and good stereo-acuity (three-dimensional vision). It would seem that a good test of personnel for such a task might be the determination of (1) the general visual acuity of the individual, and (2) the basic stereo-acuity of the individual as determined upon a good standard static test of such acuity. In the early part of the war the present speaker was involved in a situation of this sort in which it was found that the mere summation of these two tests was entirely unsatisfactory as a selective procedure for a task requiring stereo-acuity with moving objects. That is, the test of stereo-acuity with still objects did not predict the ability of individuals to deal with stereo-acuity of moving objects in a satisfactory way.

Almost everything else that will be presented in this conference will really illustrate the fact that a technical study of the human factors in the design of military and industrial equipment is of real importance for optimal operation of such equipment. It is my prediction that when the results of the many studies in this field that have been made in Russia, in Germany, in England, and especially in the United States during the present war are known it will become clear that the industrial and engineering design problems of the future must always be considered in a setting in which the known capacities of human organisms to operate such equipment are taken into consideration. One of my friends recently said that airplane design had gone as far as it could until the human organism was redesigned so that it could withstand greater forces, display greater acuities, and perform required tasks more quickly and accurately. Unfortunately, however, this humorous proposal cannot be taken seriously except in so far as human ingenuity can assist in making already known human capacities more effective under the new conditions which modern technology is developing. Above all, in the development of special procedures the psychologist is fully cognizant of the dangers of fatigue, motivation, boredom, and lapses of attention as well as in the alterations of sheer sensory-motor capacity.

In conclusion, therefore, I invite your attention to the papers which follow because I believe that they will demonstrate that in thinking about military equipment we must always think not only about

the machine as an abstract engineering problem or about the human being as an abstract psycho-physiological problem, but about the specific relationship between a given machine and a given human organism in specific operational situations. The latter task of considering the organism at work has come to be, as a result of the development of science, the field of applied, industrial psychology. It is for this reason that this field has so much significance for the future development of effective military devices.

PROBLEMS OF DESIGN OF AIRBORNE FIRE-CONTROL EQUIPMENT IN RELATION TO GUNNER PERFORMANCE

by

Dr. Karl U. Smith
NDRC Project AC-94, Applied Psychology Panel

It is proposed to discuss the problem of design of controls of air-borne fire-control equipment with reference to the armament of the B-29 airplane. The defense of this airplane is accomplished by means of five remotely controlled turrets, each equipped with two 50-calibre machine guns.

Two types of sights are employed on the standard B-29 airplane, a pedestal-type sight and a ring-mounted sight. Pedestal sights (see Figure 1) are located in the nose, tail, and right and left waist positions. A single ring-mounted sight is located aft in front of the upper-aft turret. These sights are rate-by-time, director-type, computing sights, which require on the part of the gunner simultaneous tracking, framing, and triggering. Figure 2 gives some idea of separate items of the gunner's job in relation to the components of the fire-control system. Of the various initial actions performed by the gunner, the process of preparing the sight between attacks and of slewing on target is especially important in order to wash out residual leads in the computer and to prevent the establishment of large incorrect leads before the sight is actually brought to bear on the attacking plane. It should be noted also that the tracking task of the gunner is broken down logically in terms of its pointing and rate components inasmuch as the fire control system transmits data separately concerning pointing and rate of movement of the sight by means of different electro-mechanical channels.

The extremely fast traverse rates and closing speeds of attacking aircraft on this high-speed bomber have placed extraordinary demands on the fire-control system and on the gunner. Deficiencies in firing have been noted particularly in the cases of nose and beam attacks, but, in general, the system has been successful for the type of enemy opposition which has been encountered.

The Firing Error Indicator Project, Research Division, Laredo, Texas and Project AC-94 have cooperated to secure data on trained gunners which will show the distribution of fire around an attacking target plane. This study provides information for moderate closing speeds and rates of the attacking plane. The target used was a towed glider, of 16 ft. wing span, which was flown in a crossing-over

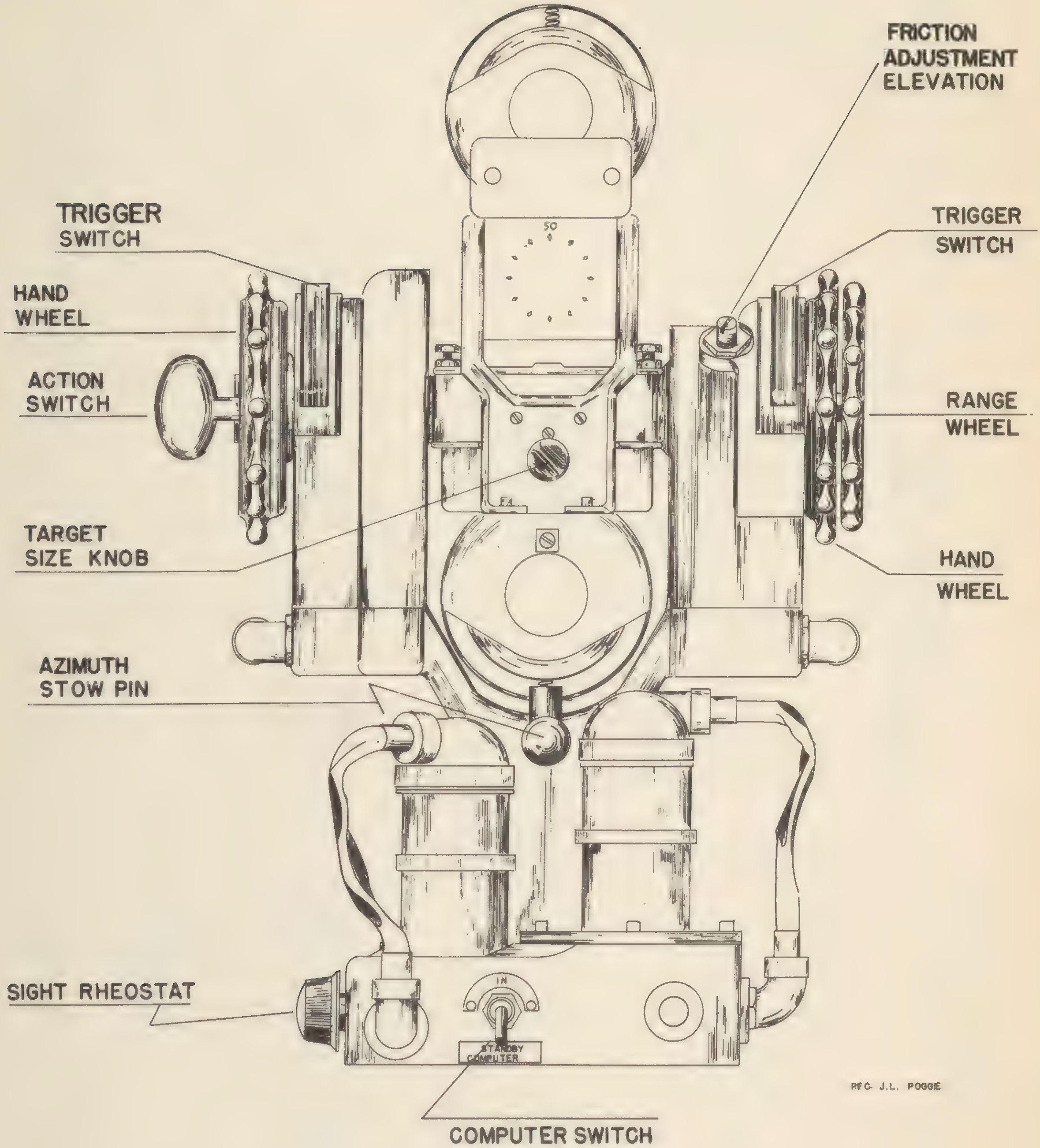


FIGURE 1

B-29 PEDESTAL SIGHT

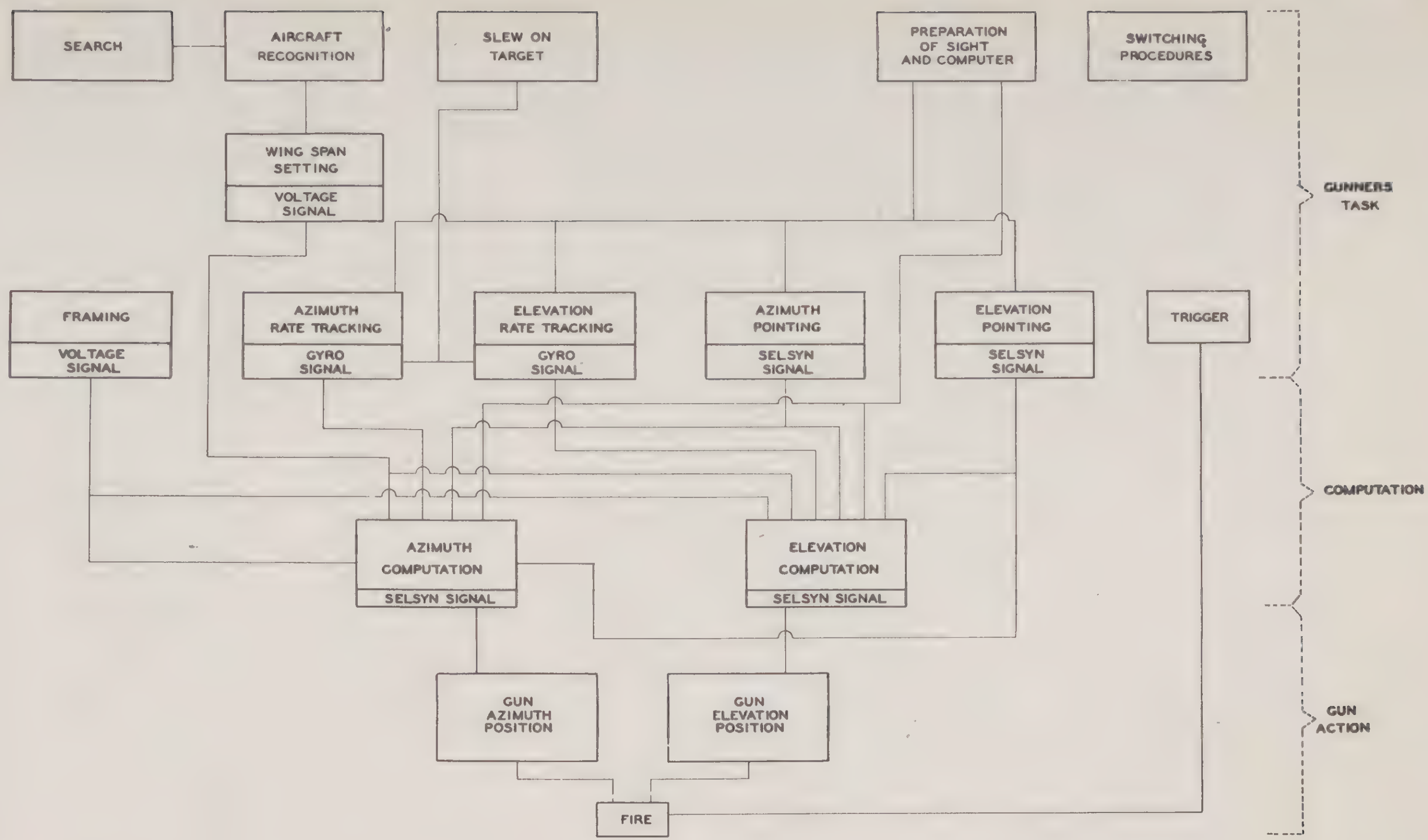


FIGURE 2

JOB BREAKDOWN OF THE B-29 GUNNER'S TASK
IN RELATION TO COMPONENTS OF
THE FIRE-CONTROL SYSTEM

attack on the tail of the bomber. In these tests, twenty-four gunners, who were carefully trained on the ground for three weeks prior to flying, fired 15,000 rounds at the towed glider from a TB-24 airplane. Bomber speed was 160 miles indicated. Figure 3 gives the results for the first three missions for the gunners used. These missions were the first times these men had ever used flexible guns in the air. Data presented are the average percent hits for the three missions for all twenty-four gunners. It will be seen that 5.7% of the bullets fell within a central target area of $2\frac{1}{2}$ yds. radius, 7% within the next area of 5 yds. radius, and 18.6% in the largest circle of 10 yds. radius. These figures indicate a firing accuracy of fairly high level for the type of attack used. An average total of 31.3 hits within a target circle of 10 yds. represents a very satisfactory concentration of fire.

Among the numerous problems which have arisen in connection with operation of the B-29 fire-control system, that of the design and operation of sight controls has been the major interest of Project AC-94. A first step made by the project on the problem of sight operation consisted of adapting time-scaled graphical methods of analysis for studying gunner performance (Figure 4). Graphical recording means were devised to register simultaneously the gunner's elevation tracking, azimuth tracking, framing and triggering on both types of B-29 sights. The development of this new method of study of gunners and of sight operation permitted understanding of various problems of motor coordination in the use of flexible gun sights of significance both to the field of training and of equipment design. Data obtained from experiments using this technique served as a basis for formulation of a set of general principles of design of sight controls, the application of which to B-29 sights are expected to improve over-all performance.

Some of the main general principles applicable to redesign of B-29 sights are considered to be the following:

1. Tracking Leverage: The tracking leverage in elevation on both pedestal and ring-mounted sights needs to be increased to permit better control of the sight and to eliminate in part elevation oscillations of the sight.

2. Manual Support of the Sight: The tracking handwheels of the pedestal sight are such that it must be supported by means of the grasp of the hand and moved primarily by means of wrist movements. The sight can be made more stable by shifting the muscular support of the sight in elevation to the base of the palm of the hand, which will also permit use of the upper arm and shoulder muscles in tracking.

3. Separation of Hand-grips: The degree of separation of handgrips on the pedestal sight is satisfactory, but on the ring-mounted

FIGURE 3

THE PERCENT HITS IN FEI FIRING AT A TOWED GLIDER, FLYING A CROSSING-COURSE ON A TB-24 AIRPLANE

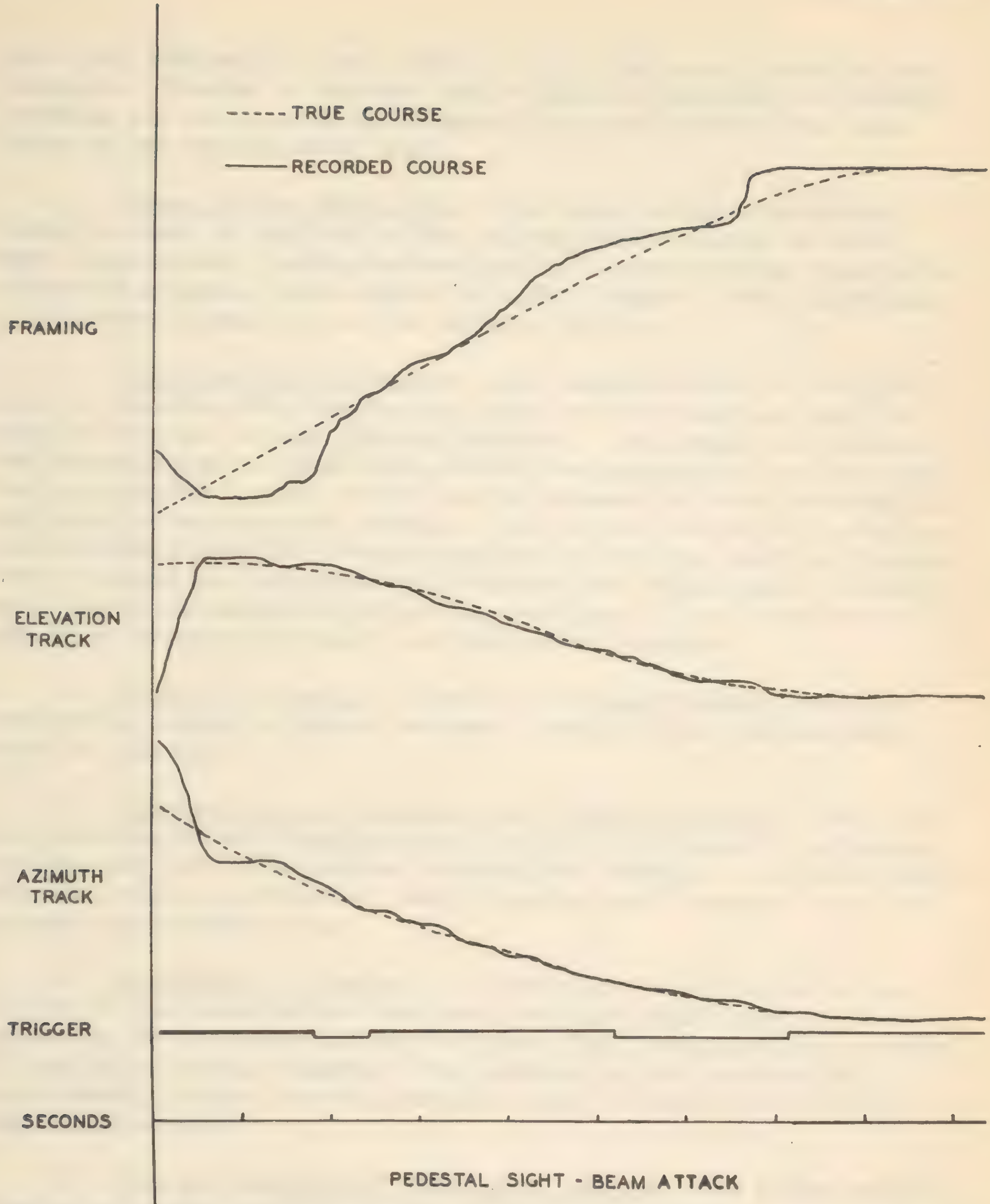


FIGURE 4

SAMPLE GRAPHICAL RECORD OF PERFORMANCE
IN SIGHTING MOTION PICTURE TARGETS

sight the arms must be bent inward to get the proper grasp on the controls. Freedom of movement and strength of movement in azimuth tracking may be improved by widening the space between the hand-grips on the ring-mounted sight.

4. Shape of the Hand-grips: The shape of the hand-grips should be made to conform to that of the gunner's hand in order that tracking and framing movements will be made without interfering effort in grasping and in order to avoid fatigue. This improvement is necessary especially on the pedestal sight.

5. Location of the Trigger: The trigger should be located so that it travels with the tracking hand and in a position near the axis of rotation of the tracking handles. The trigger, of either the index-finger or thumb type, should be arranged so that the gunner is required to make only a slight movement in order to reach it while he is tracking and framing. The trigger should be located on the hand-grip used for tracking and not on the one used for framing. These changes are necessary to eliminate the inhibition of tracking and framing movements by triggering reactions. Such interference occurs at present especially on the pedestal sights.

6. Method of Framing: A method of manual framing should be used which permits a type of movement distinct from the movements used in tracking.

7. Interrelation of Tracking and Framing Controls: The type and location of the framing control should be arranged to eliminate interaction between elevation tracking and framing, as on the present pedestal sight, or between azimuth tracking and framing, as on the present ring-mounted sight.

8. Handedness of Controls: It is preferred, because of the nature of the coordination involved, that the right hand be used primarily for tracking and the left hand for framing and for support of the sight during tracking. The pedestal sight reverses this relationship, while the ring-mounted sight is consistent with the desired arrangement.

9. Form and Location of the Action Switch: The action switch should be located and adjusted so that it is closed by a natural grip of the hand. On director-type sights like those used in the B-29, the hook-type action switch should be replaced with one that does not interfere with the movement of the hand as the sight is tracked in azimuth or elevation.

10. Damping of the Sight: A great improvement may be made possible by eliminating friction damping of B-29 sights. Such damping is unsatisfactory because of the inequality of starting and moving friction, which causes the sight to be tracked in jerky movements.

11. Stance of the Gunner: The sights in the airplane provide uncomfortable seating arrangements, which undoubtedly cause errors in sighting as well as undue fatigue. Such defects can be improved by adoption of special seats for the gunners.

As an example of the way in which defective sight design may affect the performance of the gunner, reference may be made to the effect of triggering reactions on tracking movements on the pedestal sight (Figure 5). By means of the method of graphical analysis, it has been shown that, when the gunners are required to fire by means of short bursts (5-15 rounds), they do this, once they begin to fire, in an automatic rhythmic way without reference to sighting accuracy. These rhythmic trigger responses are found to correspond in time to stepwise tracking movements, especially on the ring-mounted sight. Continuation of these triggering studies by the Research Division, Laredo Army Air Field, has indicated that the absolute number of hits with hand-held guns can be more than doubled when gunners fire continuously in comparison to firing by intermittent triggering. This figure would be increased, no doubt, with computing sights, inasmuch as the effects produced by triggering intermittently affect rate tracking as well as pointing.

In order to implement the ideas of design set forth above, Project AC-94 has been engaged in the planning and fabrication of several sets of modified controls for B-29 sights. In Figure 6 and 7 are shown one set of these controls for the B-29 pedestal sight, which has been tested experimentally. These controls follow, in general, principles, of construction enumerated, including especially redesigning and relocation of action-switches and triggers, modeling of the tracking hand-grips, and utilization of a pressure framing control.

Experimental ground tests with thirty gunners have been conducted to compare performance on the modified pedestal sight and on the standard pedestal sight. After equated training for twelve days on both sights, thirty men were tested for a period of eight days on the two sights. In all, the thirty gunners were run for approximately 6500 attacks on the two sights. Table I gives the results of the experimental tests in terms of average time-on target scores.

In terms of these combined time-on target scores, the men showed an average relative superiority of approximately 20 per cent on the modified controls during the experimental tests. A Buckingham Trainer modified by the project was used for making these tests, the results of which are being checked by air tests.

RESTRICTED

FIGURE 5

INTERRELATION OF TRIGGERING AND TRACKING

RESTRICTED

FIGURE 6

RIGHT-HAND CONTROL OF THE MODIFIED PEDESTAL SIGHT

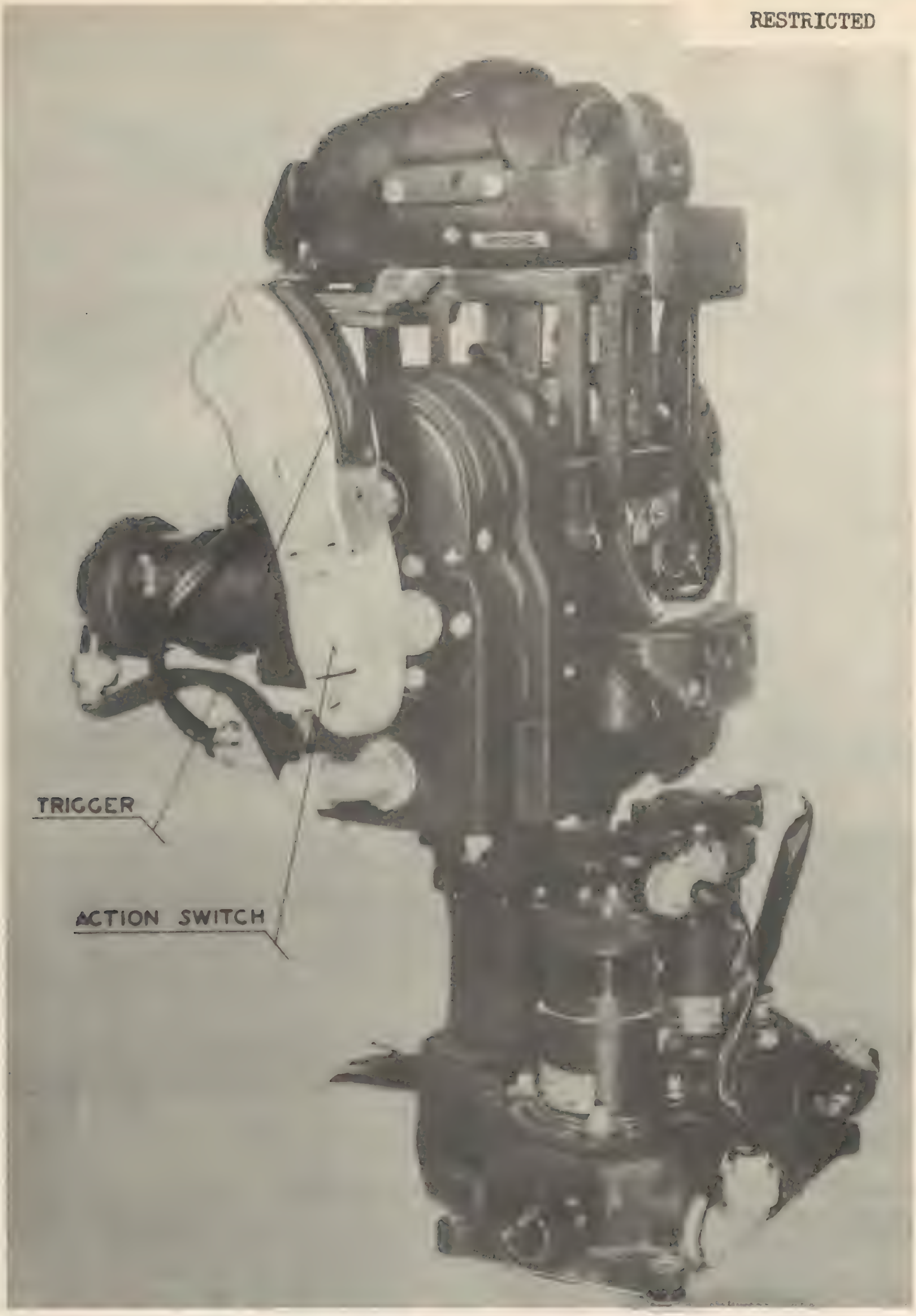


FIGURE 7

LEFT HAND GRIP OF THE MODIFIED PEDESTAL SIGHT

TABLE I

Combined Time-on Scores for the Standard Sight (ss) and for the Modified Sight (ms) Initially in Training and on Successive Four Day Period During the Experimental Test.

	Days 1-4*	Days 13-17	Days 16-20
$Mean_{(ss)}$	17.6	15.0	12.6
$Mean_{(ms)}$	21.7	18.7	14.4
$Mean_{(diff)}$	-4.1	-3.7	-1.9
t	3.87	4.58	2.57
P	.0001	.0001	.009
Percent relative superiority of Modified Sight	23%	25%	15%

*During training the gunners received a tone aid which would indicate to them when they were tracking and framing correctly.

The smoothness of control of B-29 sights has represented a major problem. A recommendation made has been that suggesting adoption of oil damping for the sights rather than the use of friction damping. Experimental tests of computer-output with an oil-damped and with the friction-damped sight have proven that an average of 24% reduction in variability of computer output occurs with the oil damped sight (Table II). These results are based on studies of ten highly trained gunners, who acted as subjects in the experiments.

TABLE II

Mean Probably Deviation in Mils of Computer Corrections

	6° Second			2° Second		
	Standard Sight (ss)	Modified Sight (ms)	Difference	Standard Sight (ss)	Modified Sight (ms)	Difference
Mean	3.26	2.49	0.77	2.13	1.59	0.54
m			0.200			0.135
t			3.83			4.00
p			.01			.01
Reduction in Variability of Computer Output			0.77=23%			0.54=25%

Work is in progress to devise an improved arrangement for seating the gunner. One step made along this line consists of a spring seat for the waist gunners (Figure 8) which permits greater freedom of movement in asimuth and elevation tracking, and eliminates much of the muscular effort of kneeling at the sight. This type of seat may constitute a real tracking aid, and at the same time prevent the occurrence of fatigue on long flights. Experimental ground tests are now being conducted with this device.

The greatest draw-back to the work of this project has been the lack of test equipment which properly combines features of training and of means of assessing sighting performance. Some of these barriers have been and are being overcome by the construction of three research and training devices: (1) an airborne sighting recorder, which will permit the securing of graphical records of sight operation in the air, (2) an airborne synthetic target system and test device, which it is hoped will provide a means of automatically scoring gunnery performance in the air under predetermined standardized conditions, (3) an R.C.T. gunnery test device which is built to apply the methods of analysis of variance to the determination of sources of error in specific types of sights and in sighting performance. This last instrument will enable us to find the main source of error in a given sight as far as gunner operation is concerned and will also provide information on the interaction between types of controls when the sight is in use.

COMMENTS BY LT. COL. EDWARD ELLIOTT, JR.
Office of Assistant Chief, Air Staff, M & S, War Department

1. As indicated by Dr. Smith, the B-29 Central Fire Control system incorporates certain undesirable features which require corrective action. In spite of these features, it is believed Dr. Smith and his colleagues will agree that the B-29 CFC system as a whole is a pretty good piece of equipment considering the "state of the art" at the time the equipment was conceived and put into production. Amplifying this statement:

a. The B-29 was the first airplane - and a pressurized airplane at that - manufactured in production quantities to be equipped with a remote control turret system of the computing type. Decision to equip the B-29 with the General Electric CFC system was not made until April 1942. Engineering and production phases had to proceed simultaneously at a rapid pace to meet the constantly expanding B-29 delivery schedule starting in the Spring of 1943.

b. At the start of the war very little was known about air-to-air firing. In the last three years a lot has been learned about the art - and it is a fact that the more we learn about

FIGURE 8

MOVABLE SPRING SEAT FOR THE WAIST POSITION ON THE B-29 AIRPLANE

aircraft fire control, the more difficult we realize the problems actually are. A good example of this is the "rise and fall" of the own-speed type gunsight. Its use in all gun positions, including the B-29, was advocated even as late as December 1944 by many aircraft fire control specialists - including quite a few in the NDRC and AAF Training Command. However, since completion of some thorough test and analysis work at Eglin Field, Laredo, and elsewhere, it has become obvious to even the most ardent own speed enthusiasts that sights of that type are not "so hot".

c. The combat performance of the B-29 CFC system has been remarkably good. An important factor responsible for this has been the small percentage of turret and gun malfunctions, which have averaged between 1% and 2%. This record is particularly noteworthy when we consider the fact that under pressurized conditions the guns and turrets are not accessible in flight.

d. Last month I visited 20th Air Force Headquarters in Guam - and all five B-29 wings in the Mariannas. The major complaint made by theater personnel relative to the CFC system was in regard to the recent removal from production airplanes of the additional parallax unit from the three double parallax computers. The APU corrects for parallax between the secondary and primary control turrets. One of our main arguments for removal of the APU was to spread the bullet pattern of the primary and secondary turrets in the plane of action to offset the errors referred to in Dr. Smith's paper which we know exist even when the gunner is ranging and tracking to the best of his ability. The main argument for retention of the APU advanced by theater personnel was that "we're doing fine with the system as is - why change?"

2. From the foregoing it may appear that I'm trying to minimize the deficiencies of the B-29 CFC system. This is not the intention - instead it is to bring to light certain salient facts of interest to this group:

a. The good results obtained with the present B-29 CFC system <u>in spite</u> of its shortcomings are due in no small part to the selection and training of gunners and maintenance personnel. The advice and assistance of the psychologists on these phases have been invaluable. It has enabled us to get the most out of the present system.

b. The B-29 CFC system is representative of many other items of war materiel, the design and operational requirements of which were not fully known or appreciated at the time the original design was accomplished - and which by necessity were rushed into production. Evaluation and analytical studies such as the one

accomplished under Dr. Smith's supervision are certain to result in constructive criticism which will enable the development and production of better equipment -- equipment which not only gets better results, but also equipment on which training can be more quickly and adequately accomplished. It behooves us to make similar studies on other items of equipment now in use.

c. In addition, it will be wise to utilize and cooperate with the facilities and personnel of training and civilian research agencies in the design, development, and test phases of new equipment. By so doing, many deficiencies which are not obvious to the engineer, but are glaring to the psychologist and training officer, can be "nipped in the bud".

3. With regard to the specific design principles outlined in Dr. Smith's paper, it will be possible and it is anticipated that those which do not require radical design changes will be incorporated in present production equipment at an early date. The remainder will be included in new fire control systems being designed for not only the B-29, but also for other aircraft in the development stage.

PSYCHOLOGICAL PROBLEMS IN THE DESIGN OF OPTICAL FIRE CONTROL INSTRUMENTS

by

Dr. Samuel W. Fernberger
Section 7.4 NDRC

It frequently happens that an engineer develops a military instrument, which may adequately accomplish the desired task, but which is designed without regard to the anatomical, physiological or psychological make-up, abilities and limitations of the prospective operator. Frequently there may be good and sufficient reasons for that particular design inasmuch as no better solution may be possible in the present state of the art or because of imposed limitations of space or weight.

There exists an excellent example of this sort of design in an Italian rangefinder in which the range knobs are so placed that the operator must raise and keep his hands some six to eight inches above his head. The position of the operator is totally unnatural and he will quickly develop extremely painful fatigue unless he has been specially trained in this operation by a long period of developing muscles which are not frequently employed in this way.

Another example is to be found in one of our American bomb sights. This is so designed that there are two sets of knobs on each side of the instrument. However, in operation, the two knobs on the one side must be moved together and then those on the opposite side must be moved simultaneously. Hence the operator must reach over with his right arm to operate a knob on the left side and then with his left arm to operate one of the right hand side knobs. This is an unnatural situation indeed and especially so when one considers that the bombardier is already in an unnatural semi-squatting position and besides has to attend to a visual presentation which he must keep in the center of attention. It is indeed understandable that bombardiers require extended training before all of these psychological and physiological functions can be accomplished with precision and sufficiently automatically so that this precision will not be lost under combat conditions.

One could multiply the examples of such situations almost ad nauseum. But the point which I wish to emphasize is that such situations, imposed by the instrument design, are unusual and unnatural for the normal human adult.

The NDRC Section, to which I am attached, has been concerned primarily with optical ranging instruments. It is well known that both American Services adopted optical range finders of the stereoscopic type. It is the task of the range finder operator to

manipulate a range knob so that the target is brought to the same apparent distance in space as a fixed mark which is also in the field of vision. These optical rangefinders utilize only the psychological cue of visual disparity of the images in the retinae of the two eyes. The ideal of accuracy is measured by a parallactic angle of 12 seconds of arc at the eye. That this is indeed the ideal aimed at in operation is apparent because both Services have designated the 12-seconds angle, one Unit of Error.

Experience has indicated that very few Service personnel can make observations with the stereoscopic rangefinder as accurately as this. Hence the Services are faced with a selection problem to determine those individuals with sufficient ability to give promise of reaching such an accuracy level even after training. And after such selection, which indeed skims the cream of the total Service population, their experience has shown that a long period of training is necessary to bring even these selected men up to or near the expected ideal of accuracy. Even in war time, it has been found that a period of training of many weeks is required to develop reasonable proficiency in the operation of such a stereoscopic ranging instrument. And experience shows that, even with such selection and such intensive training, a good percentage of these men never reach and maintain the desired level of accurate observation.

What I shall wish to show is that probably much of this difficulty is due to an unusual and unnatural situation imposed on the operator by the design of the instrument. This is to be considered only as one of many examples which might be cited.

Some years ago, under NDRC auspices, Professor Alfred H. Holway of Harvard University began a series of experiments to analyse stereoscopic vision both with telescopic vision and with the unaided eyes. Many of his experiments were performed in the laboratory but many of them were repeated over land and water to verify the findings. In these field trials, realistic ranges were employed up to beyond 6,000 yards and magnifications were used from one (the unaided eye) to 40x.

In his earliest experiments, Holway found that his observers, with or without magnification, exhibit a far better accuracy than one obtained with the conventional stereoscopic rangefinder. The differences were so striking that it seemed worth while to determine why natural stereoscopic vision was so immensely superior to the results obtained with a military instrument.

These investigators first eliminated the cue of binocular parallax and found that the observers could still make distance judgments, not so accurate as when parallax cues were present but still surprisingly proficient. They next eliminated size change cues and

found a further decrease in accuracy but determined that the observers could still make surprisingly reasonable distance judgments. The one further reasonable possibility seemed that, with both parallax and size cues eliminated, the observers must be utilizing wave front differences as cues. Hence they collimated the light beams from both target and reticle so that the wave fronts in both cases were plane. With this additional cue eliminated the observers were unable to make any distance judgments whatsoever.

The investigators then determined quantitatively the values of each of these kinds of visual cues and discovered that the order of magnitude of accuracy was parallax, size difference and wave front difference. They also found that these cues summated, namely, if one added the accuracies obtained for each of the three cues in isolation, the result was extremely close to the value which one obtained in natural vision when all three cues are present.

Hence it is true that the conventional stereoscopic rangefinders utilize the most important of the three visual cues but they totally ignore the other two which, when present, very considerably increase the accuracy of observation. Indeed, and there is no direct evidence on this point at present, it may well be that the constancy of size and wave front in the present stereoscopic ranging instrument may act as false cues so that one is not able to utilize to its maximum extent the parallax cue which is present.

I may seem to have wandered a long way from the subjects of this conference, which has to do with training in military situations. But I want to emphasize that the design of the conventional stereoscopic rangefinder presents a perceptual situation to the observer which is unnatural and unusual. Throughout his entire life his distance vision has been based upon three essential cues, parallax, size change and wave front change. The stereoscopic rangefinder operator, at the beginning of his training, is faced with a situation where two of these usual cues are eliminated and he must make his judgments by the single parallax cue along. This requires practice and training in exactly the same way as the normal individual, who has suddenly lost one eye, must learn to make distance judgments with the parallax cue eliminated.

Experiments are in progress at Harvard University, but not yet completed, with a relatively large group of naive subjects. The preliminary results seem to indicate that little or no training is required for the natural "all cues" present situation while, as Service experience has shown, considerable training is necessary when the parallax cue along is available for the observer. There is also some evidence that the selection problem is also much less critical for the situation when all three cues are available. These investigators are also designing and developing a stereoscopic ranging instrument which will present all three cues to the observer.

As I pointed out at the beginning of this paper, limitations of size, space, weight or available personnel for the job may impose upon the designer the necessity of producing an instrument whose operation is unnatural and unusual or unduly complicated. The problem then is to determine the best training routine to obtain maximum efficiency in the shortest possible time with the instrument as it exists.

An example of this sort is to be found in the flexible gunnery situation where a single operator must simultaneously track in two dimensions, do stadiametric ranging and trigger his gun at the appropriate moments. These are a lot of operations for a single man to accomplish at one time with any high degree of efficiency. Experiments in regard to reticle design for such an instrument were performed at the Foxboro Company. Some early results, under field conditions, performed by the Foxboro Company, indicated that an airplane was comparatively safe on an incoming or outgoing leg when simultaneously ranged and tracked by untrained operators, even though they were of Officer rank.

When the experiments were moved into the laboratory, it was obvious that no differential results for reticle design could be obtained until there had been developed a competent trained group of observers. Hence this necessity gave an opportunity to train matched sub-groups in different ways. Triggering was never attempted throughout the experiment. One group were trained from the beginning in simultaneous bi-dimensional tracking and stadiametric ranging. A second group was trained first in tracking and then ranging was added. And the third group were started with stadiametric ranging first and later tracking was added. The results show clearly that both groups for whom the complex problem was broken up in their training reached a given level of competency for the whole operation considerably sooner than the first group who were given the whole complicated operation en masse from the start. It turned out that the group who started with tracking alone were slightly superior in rapidity of learning the whole operation to the group who started with ranging. Hence these results, which are really only a bi-product of the main experiment, clearly indicate what the training program should be for this complicated and unusual, if not unnatural, operation.

It seems to me that the conclusions to be drawn from this discussion are fairly obvious.

1. The designer of military instruments should avoid requiring anything unusual or unnatural on the part of the operator either perceptual in the presentation or on the side of operational reaction. In this way, a training program will be minimized.

2. If certain limitations make such a solution impossible, then an investigation of the best training program should be determined

and this should be adopted by the Services simultaneously with the issuing of the instruments to the using personnel.

And how may these objectives be accomplished? At the present time, it seems worth while to have a competent psychologist study the plan of new instruments while they are still in the design or mock-up stage, or, at least, before the design has been finally crystallized so that he may point out such unnatural situations and possible aid in determining how they may be eliminated. If such elimination is not possible, or even if it is possible, a training program should be developed so that it may be issued to the using personnel at the same time with the new instrument.

COMMENTS BY COMMANDER S. S. BALLARD
Bureau of Ordnance, Navy Department

I agree with the thesis and the conclusions stated by Dr. Fernberger, which can be paraphrased as follows:

(a) The training program will be minimized if the designer of military instruments avoids requiring from the operator anything unusual or unnatural, either perceptually or operationally.

(b) When this cannot be done completely, special attention should be paid to the immediate initiation of the best possible training program.

It is the unfortunate fact that it is very often impossible to arrive at designs which incorporate all the desiderata which the psychologist may state. To be sure, there are situations in the design of instruments and of ensembles such as gun directors and turrets where the services of a good practical advisor, disinterested and hence unprejudiced with regard to technical design matters, could make some very helpful suggestions -- this person might well be a psychologist. But unfortunately there are many instances where other considerations make it impossible to meet all the purely scientific conditions that might be imposed. Let me take what is possibly the best-known stereoscopic illustration, the ordinary field glass or binocular. The 7-power binocular magnifies the field of view laterally seven times, but does not do nearly as well in "fore and aft" magnification. Therefore the visual field seen through such a glass is very badly distorted. This can most readily be observed if one looks first with the naked eye and then through a binocular at a vehicle which is approaching or receding. The remedy for this deficiency of binoculars would be the impractical one of designing a 7-power glass so that its objective lenses are seven times normal

interocular distance, or about 18 inches, apart! This would of course result in entirely too unwieldly and heavy an instrument for hand-held use.

Now let us turn to the much more difficult problem of designing what from the visual point of view would be the best of all possible stereoscopic rangefinders. We have been aware for some years of the fact that the naked eyes, at least those of certain individuals, can exhibit amazing stereoscopic acuities -- acuities of the order of one or two second, which is far better than the Army-Navy "standard" of 12 seconds quoted by Dr. Fernberger. Unfortunately, however, it appears that when such sharp eyes look through an optical instrument, at least one that includes lens systems, this high acuity is immediately degraded by the aberrations of the optical system. It may well be, at least at short ranges, that these degrading factors are of the nature proposed by Professor Holway, namely, size differences between moving target and fixed reticle and what he calls "wave-front differences". Following the lead of research conducted by the Polaroid Corporation under NDRC auspices, the Bureau of Ordnance in 1942 embarked upon the design of an instrument which would at least partially meet the optical objections to the conventional stereoscopic rangefinder. This project was subsequently terminated, however, for reasons which had nothing to do with the scientific principles involved.

In connection with the elimination of size differences and focus differences mentioned in Dr. Fernberger's paper, it is interesting to note that in the early part of the century the English firm of Barr and Stroud constructed a pseudo-stereoscopic rangefinder which eliminated these false clues. It also eliminated contrast difference, which, although not mentioned by Dr. Fernberger, and apparently not investigated in Holway's experiments, has been found to be more harmful as a false clue than the size or focus differences encountered in fire control rangefinders. Although it undergoes periodic reexamination and scrutiny, the pseudo-stereoscopic design has never proved to be practical in service.

The NDRC has conducted for well over four years a continuous program, which at times was of pretentious size, on the investigation of stereoscopic vision and stereoscopic rangefinders. Among the results of this program can be quoted the following: Real contributions in outlining procedures for the selection of rangefinder operators and for the evaluation of rangefinder performance; the initiation of the design and construction of several new rangefinders which incorporate somewhat altered optical and mechanical principles; improvements of existing stereoscopic rangefinders in the reduction of stratification and parallax errors. However, it is illustrative of the subtlety of this highly technical field that up to this time no new certainties have been introduced which have permitted the incorporation into stereoscopic rangefinders of any fundamental improvements which meet

the perceptual criticisms put forth by Professor Holway and Dr. Fernberger. It is hoped that psychologists or others will eventually demonstrate further practical improvements in stereoscopic rangefinders, and hence effect a simplification of the considerable training program now required for rangefinder operators.

PROBLEMS IN THE DESIGN OF RANGEFINDER RETICLES

by

Dr. C. H. Graham
Applied Psychology Panel, NDRC

Introduction

It would be impossible, within the time limits available for my report, to give a full discussion of all of the factors in reticle design which determine the stereoscopic performance of rangefinder personnel. For this reason I shall restrict myself to consideration of two important aspects of the topic.

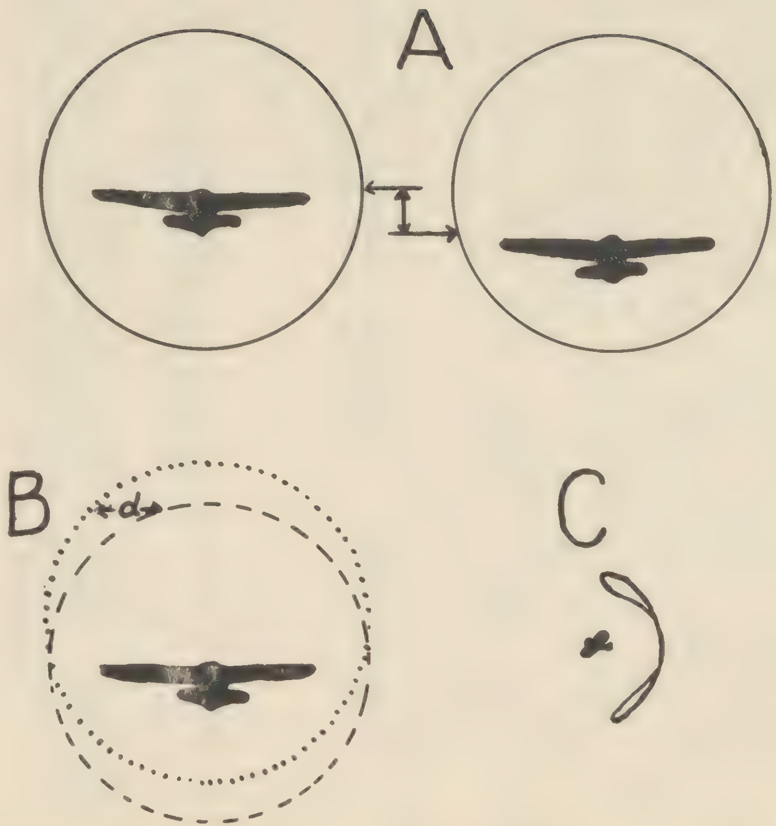
Performance as a function of height of image adjustment

The variability of observer performance is greatly affected by a condition known as "height break". Height break occurs when the positions of the target images for the left and right eye vary in elevation with respect to the reticle. In the operating situation it occurs when improper height of image adjustments are made.

An example of height break is shown in Figure 9. In this figure the reticle is a circle. The observer regards the reticles in Figure 9A, and under proper conditions of instrument adjustment, the two circles are fused if the target for the left eye is in the same position relative to the reticle as the target for the right eye. In Figure 9A this latter condition is not encountered. The target for the right eye is, relative to the reticle, lower than the target for the left eye.

Figure 9B gives a diagram representing a projection on a hypothetical "fusion center" (within the observer) of the target and reticle combination of Figure 9A. The target is represented as fused a condition holding under usual circumstances. The reticle is single but appears in a distorted manner.

A conceptualized view of what the observer sees as he looks at the two fields of view in the rangefinder is given in Figure 9C, where it is supposed that a hypothetical observer is regarding, from the side, the hypothetical visual objects which the stereoscopic observer regards through the rangefinder eyepieces. The objects as seen from the conceptual viewpoint consist of a target, localized in space, and a circular reticle twisted out of shape in such a manner that the highest and lowest points of the circle seem nearer to the stereoscopic observer, the middle part being farther away. The



A: An example of height break for a circle reticle. The position of the target is higher in the left eye than in the right eye.

B: The condition of fusion holding for the reticles when the target is properly fused. The dotted circle represents the circle reticle for the right eye; the dashed circle, the reticle for the left eye. d is resulting disparity.

C: Conceptual appearance of B, as projected in space and seen from the side of the reticle and target.

FIGURE 9

amount of distortion is not a small matter, for it can be shown that, relative to the size of the plane, it is considerably larger than is indicated in the diagram. Obviously, when a reticle shows such an appearance, it is impossible for an observer to range on a target, for the observer does not know which part of the reticle to use for reference. In other words, great inaccuracies may come about due to a condition of height break. In extreme circumstances, ranging is impossible.

Consider some theoretical aspects of the distortion. Figure 9B indicates that, when the target images are fused, the reticles for the two eyes provide conditions of retinal disparity, as indicated by the symbol <u>d</u>. Points on the reticle for the right eye fuse with horizontally aligned points for the left eye, but because the disparity, <u>d</u>, varies as a function of the condition of "height break", horizontally aligned points for the two reticles have different disparities, and hence points on the fused reticle appear at different ranges.

The circle demonstrates height break effects in an extremely striking manner. However, it may be shown that deleterious effects due to height break occur whenever curved or slanting lines are used. Figure 10 indicates results which have been obtained with a great number of reticles and under various conditions of height break. It will be seen that some of the reticles give a very great increase in variability of performance as "height break" increases, whereas others do not. In particular, it should be noted that the Navy diamond reticle is poor in this regard, whereas a reticle which presents simple vertical lines, as in Figure 11, shows very little change in precision of performance as height break increases.

The reticle of Figure 11, a vertical line reticle with fore and aft marks, is extremely resistant to height break and is one which has been recommended to the Navy.

<u>False fusion</u>

Another interesting group of psychological effects centers about the problem of "false fusion".

Figure 12 represents the effect. Figure 12A shows a view of the field for the left eye and for the right eye. (Numbers above the reticle marks are presented for ease in identification. They are,of course, not present in the reticles themselves.)

When the right and left eye views of Figure 12A are fused properly, the observer sees the view of Figure 12B; a view consisting of three fused lines hanging in space, where lines 1 and 4, 2 and 5, and 3 and 6 are fused. However, it is possible for an anomalous

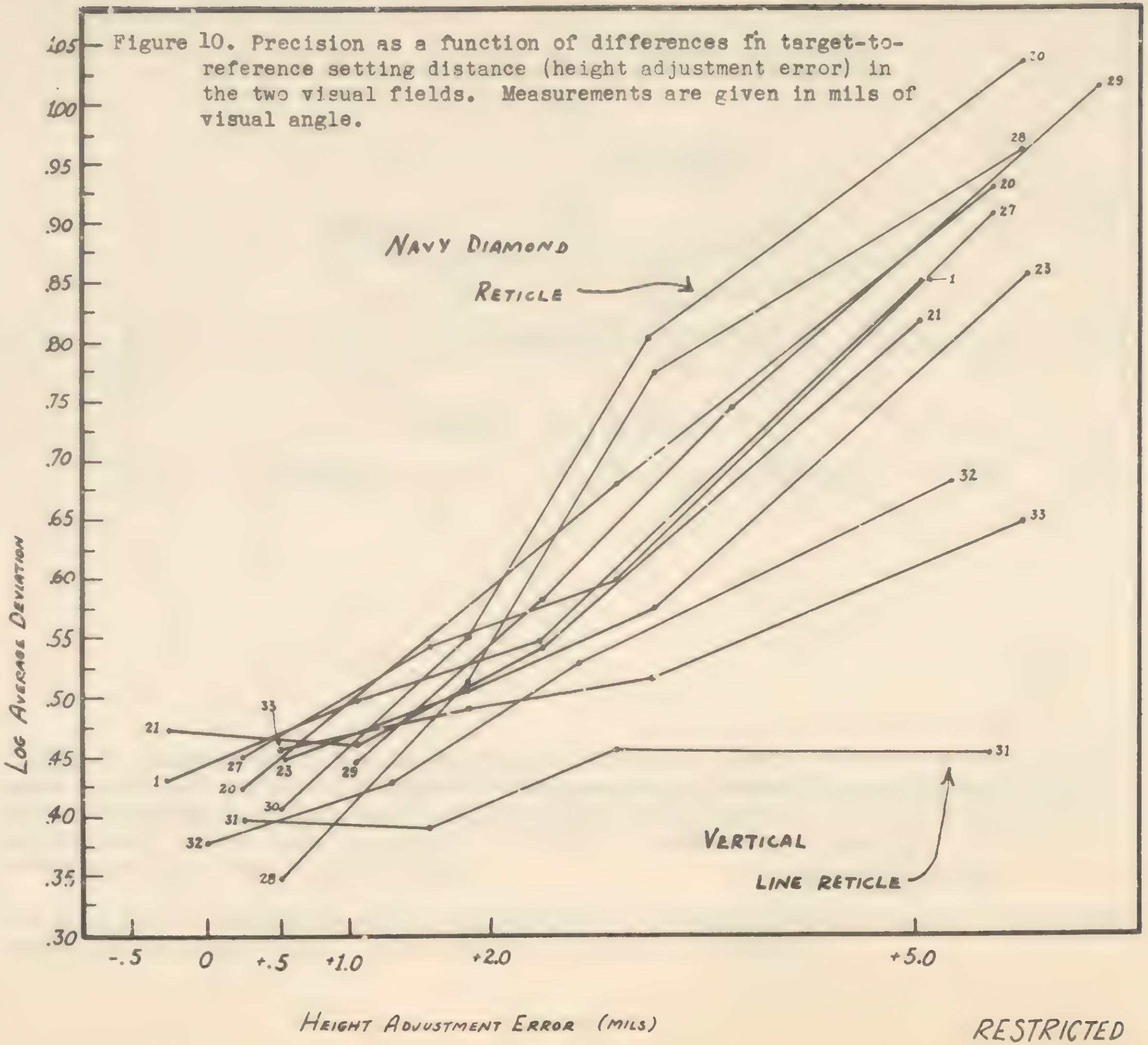


Figure 10. Precision as a function of differences in target-to-reference setting distance (height adjustment error) in the two visual fields. Measurements are given in mils of visual angle.

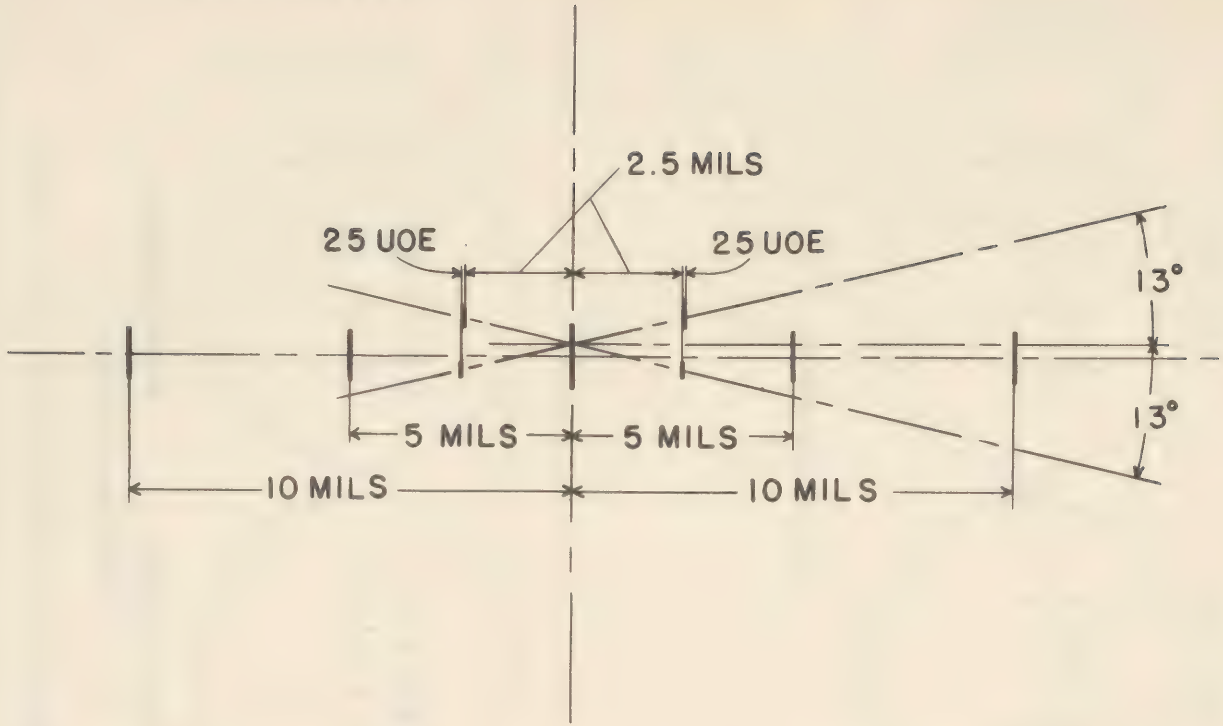
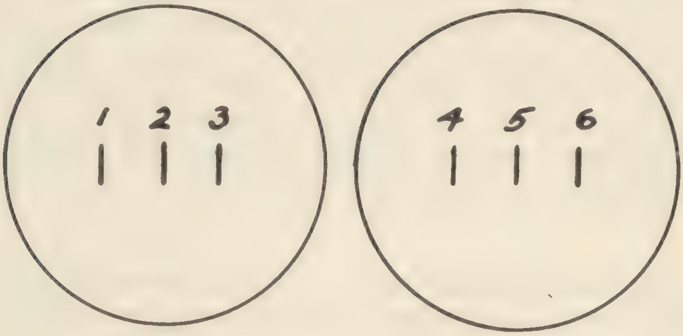


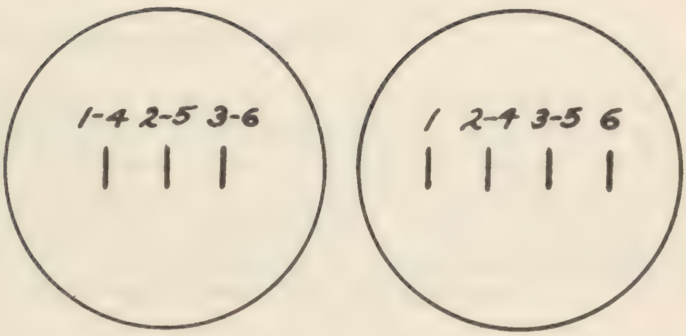
FIGURE 11. Drawing shows positions of fiducial marks in left field (with fore and aft marks seen as at 24 power). Right field appears as a reverted image of left field. The fore and aft lines are inclined 13° toward the horizontal axis and intersect on the vertical center line at a point 1.00' above center line of reticle. All mil measures are in terms of true field.

The fore and aft marks are offset 25 UOE from the central measuring mark. Fore marks appear in the upper field, and aft marks, in the lower field.

LEFT EYE RIGHT EYE



MONOCULAR VISION



CORRECT FUSION FALSE FUSION

BINOCULAR VISION

Figures Above Fiducial Lines Not Present In

Real Reticles, Used Here For Line Identification.

FIGURE 12

condition of fusion to occur where line 1 is unfused with any line of the right eye reticle; line 2 is fused with line 4; line 3 is fused with line 5; and line 6 is unfused. The unfused lines take up the spatial position dictated by the fused lines, and the whole configuration appears in the space assigned by the fused lines. The lines of sight to the reticle under the latter conditions are more divergent than is the case under proper fusion conditions. For this reason, the reticle seems further away to the observer than it does when proper fusion occurs. At any rate, the net result of "false fusion" is to make it possible for the observer to establish contact between the target and the reticle at more than one setting of the range scale, i.e., for a position of true or false fusion. How many of such settings can be made, and whether or not they can be made, depends upon the geometry of the reticle design.

A simple preventive of false fusion consists in placing fore and aft marks in the reticle. The provision of fore and aft marks makes it impossible for incorrect fusion to take place without a perceived doubling of the fore and aft marks. Because of the fact that fore and aft marks have been judged to be useful in "spotting" as well as in preventing false fusion, they are valuable additions to the principal reticle configuration. In addition, we have shown experimentally that fore and aft marks do not decrease resistance to height break.

Other devices may be used for guarding against false fusion, but time does not permit their full consideration.

<u>Other factors in reticle design</u>

It would be possible to speak of a number of factors in reticle design other than those enumerated. Particularly in the case of illuminated reticles (i.e., reticles in which the lines are brighter than the background), it would be important to consider the problem of optimum reticle illumination. These and many other questions make the topic of reticle design an important practical problem for both the instrument maker and the psychologist.

COMMENTS BY LIEUTENANT N. H. PULLING
Bureau of Ordnance, Navy Department

At first thought it might appear unnecessary to devote a program of research to the design of rangefinder reticles. Stereoscopic rangefinding, however, is one of the most complicated and misunderstood of visual functions. As a result, it is not surprising that the precise manner in which the measuring marks on the reticles

contribute to the accuracy of a rangefinder has been in the past a matter for speculation rather than of fact. Dr. Graham has investigated this problem with such care and thoroughness that a firm foundation of understanding has now been achieved. His experiments not only have embraced the design of conventional opaque reticles, but also have guided the development of illuminated, projected-reticle systems, concerning which no information was available.

Since Dr. Graham has just commented at some length on height-of-image errors in stereo rangefinders, I will mention some of the practical implications of this work.

In naval rangefinding, range errors often occur because precise height adjustments are very difficult to make under many conditions afloat and because the accuracy of such adjustments is decreased by deformation of the supporting tubes of the rangefinder. As would be expected, the longer base rangefinders are extremely subject to bending and movement of parts as a result of temperature changes, vibration, and the shocks of gun fire. Antiaircraft rangefinders, moreover, incur height-of-image errors as a result of asymmetrical sag of the inner tube at high angles of elevation.

On the basis of Dr. Graham's recommendation, the Bureau of Ordnance is incorporating a 5-line reticle pattern into antiaircraft Rangefinders Mark 42, which are being procured currently for use in Gun Directors Mark 37, the dual purpose directors used in all modern battleships, cruisers and destroyers in controlling the fire of 5-inch guns. Subject to substantiating service trials, this improvement will be adopted as a standard design in all stereo rangefinders manufactured for the Navy. The practical advantages expected from this portion of the NDRC reticle studies are hence: First, the elimination of range errors caused by unavoidable changes in the relative heights of the target images; second, removal of the need for making a careful height adjustment at the beginning of each watch.

In conclusion, the results of Dr. Graham's comprehensive reticle research constitute a significant contribution to our knowledge of rangefinder design.

PSYCHOLOGICAL PRINCIPLES IN THE DESIGN CONSTRUCTION, AND USE OF SYNTHETIC TRAINERS

by

Dr. Dael Wolfle
Applied Psychology Panel, NDRC

Trainers are intended to help train men for combat. Their only reason for existence is to give men skill in the operational use of their weapons. The need for a trainer arises because a training problem exists. It is used as part of a training program. Its value depends on what it contributes to training. The sole purpose of a trainer is, in short, to train.

Furthermore, a trainer should simplify the task of military training. This it does by being safer and cheaper, and by being available when operational equipment is scarce or cannot be used because of weather conditions. Men can practice on a tracking trainer when real targets are unavailable. They can practice on a Link Instrument Trainer in perfect safety in any kind of weather, and at relatively little cost.

If the value of a trainer is to be as great as possible, it must be designed to take full advantage of the abilities of the men who will use it. The designer, or one of the designers, should therefore have an intimate and detailed knowledge of human capacities and limitations, of how men work, and how they work most efficiently, and of what interferes with efficient operation and learning.

I will give two illustrations of how a knowledge of the human factors involved could have improved specific trainers if that knowledge had been utilized when the trainers were designed. The first illustration is the basic trainer for the SCR-584.radar. In this radar, range tracking requires the adjustment of a rotating pip to a rotating hairline. The Massachusetts Institute of Technology Basic Trainer for this radar naturally duplicates the rotating hairline feature.

The Applied Psychology Panel project on the Selection and Training of Radar Operators conducted an experimental comparison of tracking to a rotating hairline with tracking to a fixed hairline.

The results of the experiment are shown in Figure 13. The upper curve shows the average daily error scores of 25 men who learned to track to a rotating hairline. The lower curve shows the average daily error scores of 18 men who learned to track to a fixed hairline. Since the points on each curve represent errors, the lower curve shows better performance. In 5 days the men using

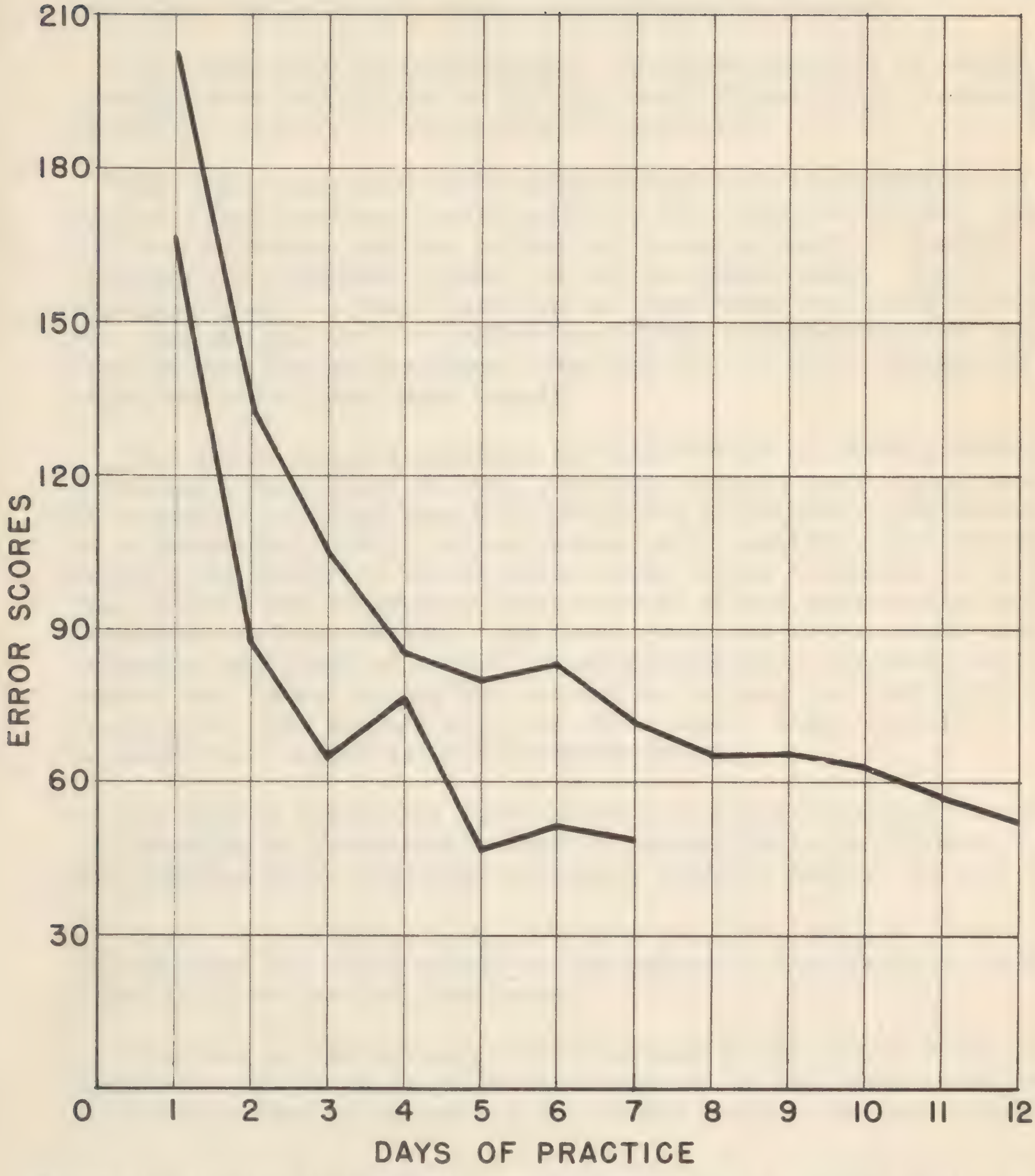


FIGURE 13. Learning to track with a fixed hairline and a rotating hairline on the Radar SCR-584 Basic Trainer. Each curve shows the learning progress of a group of men learning range tracking with the SCR-584 basic trainer. One group (the upper curve) tracked to the standard rotating hairline. The other group (lower curve) tracked to a fixed hairline. Five days of practice with the fixed hairline produced as much improvement as 12 days with a rotating hairline.

a fixed hairline became as good as the men trained with a rotating hairline became in 12 days. The difference between the two groups was highly reliable and cannot be attributed to chance.*

The conclusion is inescapable: Men could learn to do range tracking more rapidly on the SCR-584 Basic Trainer, and presumably on the 584 itself, if the hairline stood still.

But now we run into the practical fact that the hairlines do rotate. The instruments were built that way and are in use. The difference between the two methods of tracking does not justify changing the equipment already in use or construction. But if the superiority of the fixed hairline had been known and considered at the time the 584 and its trainer were being designed we might now have an even better instrument than the 584 is, and a trainer on which men would learn more rapidly

The second example involves the improvement of scoring devices. A scoring device found on many tracking trainers uses a phototube to actuate a recorder when a target light is tracked. The design of a phototube recorder raises several very specific questions concerning the radius of the circle in which a man is scored as being "on target"; and concerning other details of the construction and sensitivity of the device. How these questions are answered will influence the range of scores, their reliability, and their effectiveness both in motivating the men and in helping the instructor to train them. The answers will, in other words, help determine how valuable the trainer is as a training device.

An Applied Psychology Panel project on Psychological Problems in Operation of Antiaircraft Lead Computing Sights and Directors has attacked these questions and given specific answers to each one.**

Here, as a sample, is one specific question, and its answer. The question is: What should be the radius of the circle in which a man is scored as being on target?

The size of the scoring circle determines the scores which men will make. If it is large, good scores can be made easily and there will be a piling up of perfect and nearly perfect scores as shown in

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*Comparison of range tracking methods: Tracking to a fixed hairline versus tracking to a rotating hairline. OSRD Report No. 3858. July 4, 1944. (Confidential)

**Notes on the design of phototube scoring devices for tracking trainers. NDRC Project N-111, Informal Memorandum No. 9, May 23, 1945. (Restricted)

Figure 14. The poor men, however, will be spread out, making it easy to tell the very poor ones from those who are only moderately poor. On the other hand, if the scoring circle is small, good scores will be very hard to make and there will be a piling up of zero and low scores, as shown in the lower curve of Figure 14. The good men will now be spread out, making it easy to tell the very good ones from those who are only moderately good.

The answer therefore is that the size of the scoring circle should vary, and should depend upon the tracking ability of the men in whose scores one is interested.

A mathematical analysis of this situation and of the distribution of tracking errors leads to the more specific statement that the radius of the scoring circle should be 1.13 times the average tracking error of the group within which the maximum differentiation is desired.

If the men are well trained, and if it is desired to select the very best trackers, the radius should be small, 1-1/8 times the average tracking error of the good trackers. If the objective is to weed out the poorest men, the radius should be large, 1-1/8 times the average error of the poor trackers.

If the psychologist works with the engineer when a trainer is being designed, the scoring system can be made to fulfill these conditions.

Both of these examples have illustrated advantages of cooperation between the engineer and the psychologist. Such cooperation should generally be possible without serious loss in either engineering or psychological efficiency of the trainer. From an engineering standpoint there will usually be several ways of accomplishing the same purpose, several ways in which the controls can be placed and manipulated. The psychologist can indicate which of these will probably make the trainer most effective. From a psychological point of view there will usually be several mechanisms which will achieve the same purpose. The engineer can indicate which will work most efficiently and be least likely to create maintenance difficulties. Working together, the engineer and the psychologist should develop a more useful trainer than either can design along.

When a trainer is built and ready for use, knowledge of learning and motivation - the human factor again - is also important. For training can be good or bad. Trainers can be used effectively or they can merely fill in time.

Figure 15 shows the learning records of two groups of men given practice on the Philco Trainer for the SCR-270-71 radar. The upper

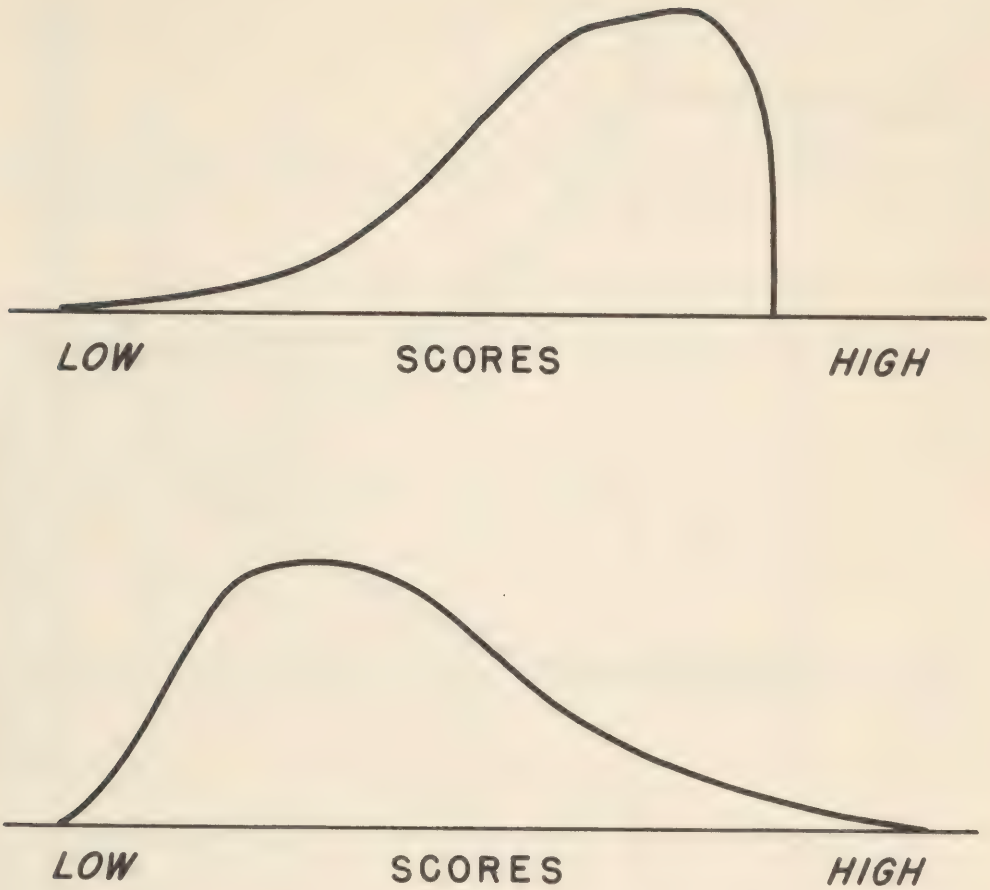

FIGURE 14. Distribution of tracking scores for different sized scoring circles. If the scoring circle is large, high scores are easy to make. The distribution of scores will approximate the upper curve. If the scoring circle is small, high scores will be difficult. The distribution will then approximate that of the lower curve.

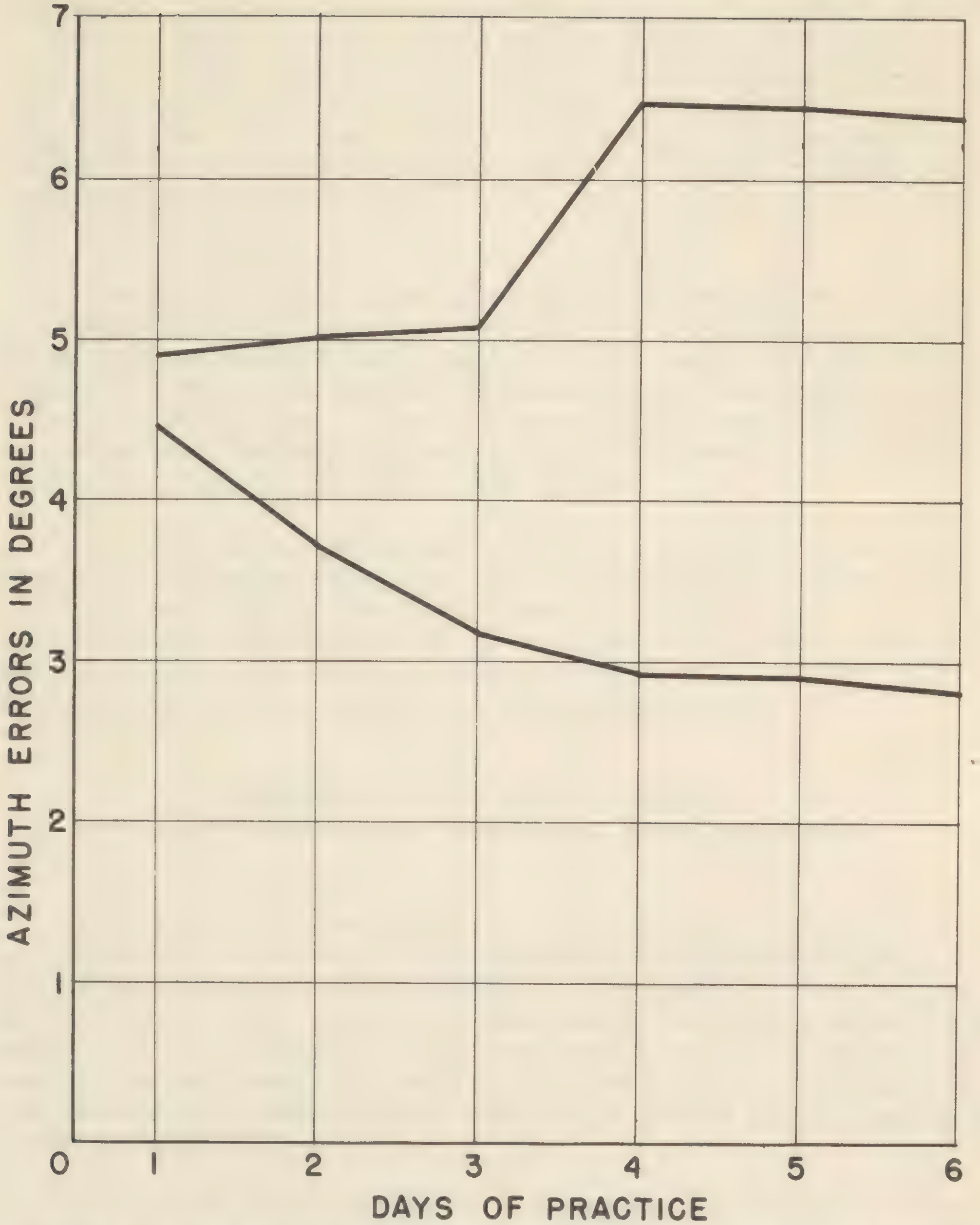

FIGURE 15. The effects of good and poor training on the Philco Trainer for the SCR-270-71 Radar. The upper curve shows the daily error record of a group of men trained under a poorly organized and taught program. The men got worse and worse under these conditions. The lower curve shows the record of another group. These men were given good training. They got steadily better and better as practice continued.

curve shows the record of the men trained at one Army base. They made larger and larger errors as practice went on. A psychologist studied this situation and made a number of recommendations for improving the training. The lower curve shows the result - the steady improvement of another group of men trained on the improved program at another Army base. Each day they made smaller errors than on the day before. The same kind of men, the same trainer, and approximately the same training time were found in the two places. Well-planned instruction and drill in one base led to improvement. Poorly planned and haphazardly supervised instruction and drill at the other wasted the time of many men.

The psychological principles of good instruction on a trainer are essentially the same as those for any other type of training. These principles have been described in a memorandum on synthetic trainers*, which the Applied Psychology Panel has recently distributed to many of you. Since the same principles will be illustrated in several of the papers given in this afternoon's session of this conference, we will not take them up now.

In conclusion, the human factors are of central importance in designing and using trainers, for the trainers sole purpose is to improve human skill. This improvement in skill will be greatest and most rapid if the trainer is designed and its use planned to help men learn, if emphasis is placed on the man as part of a man-machine combination, and not on the machine alone.

COMMENTS BY CAPT. LUIS DE FLOREZ
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With regard to the statement that "The sole purpose of a trainer is, in short, to train". This statement seems restrictive. Trainers may often be used in the selection of personnel, either on the basis of aptitude or with respect to proficiency in skills acquired on the same or other trainers. Also, many have proved very useful in the evaluation and design of service equipment since, in them, the human and mechanical elements which combine to make a combat team may be observed and scored together.

In listing the advantages of synthetic training, Dr. Wolfle has omitted one important advantage provided by synthetic trainers. This is that an instructor can observe and correct a student's errors <u>at the time they are made</u>.

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*The use and design of synthetic trainers for military training. OSRD Report No. 5246, July 6, 1945. (Restricted)

In the pressure of wartime training programs, the design of a trainer must often be a compromise between psychological and engineering deciderata on one hand, and expediency in development and production on the other. Experiments such as described in paragraph 6 can not be made until a model is built but necessity may force a device into production before such tests and redesign can be completed.

These same considerations apply to the design and production of service gear for combat. The important thing, both for trainers and service equipment, is that such experiments be conducted as early and as expeditiously as possible and that the changes they indicate be put into production lines as fast as front line needs permit.

Truly, in synthetic training, almost nothing can be accomplished without proper utilization by competent instructors and proper maintenance.

PSYCHOLOGICAL PROBLEMS IN THE DESIGN OF NAVY FIRE CONTROL EQUIPMENT

by

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Several of the previous speakers have pointed to the desirability of making careful operational studies of pilot models or pre-production models of military equipment. Spotting oversights or errors in operational design at an early stage in the development of a piece of equipment, makes it possible to remedy these features in final production models.

The project with which we have been working in the Navy Yard here in Washington was set up to study the operation of the new, light-weight, handlebar-operated Navy gun directors. Six different directors of this type have been developed. In the case of the last five, preliminary models were sent to the Ordnance and Gunnery Schools in the Navy Yard so that early maintenance instruction on the equipment could get under way. At the same time, the equipment was available to our project for study, examination, test and criticism. Although the number of operating difficulties and design errors found in these new directors was greater than would have been found in directors developed slowly and systematically in peacetime, our observations point to several conclusions which should be generally useful guides in equipment development. These are:

(1) Engineers should consider not only the most efficient design of unit parts of equipment but also the general layout of the complete system, and should design a unit part on the basis of the relation of that part to the rest of the system.

(2) Equipment design should be carried out with the training problem in mind. Wherever possible, devices or features which will make training easier should be incorporated in the original design of the equipment.

In the time allowed, I would like to offer a number of illustrations of design problems related to these conclusions. The illustrations all refer to the design of the small Navy gun directors. As a general introduction to this type of equipment, let us look at a simplified drawing (Figure 16) of the Gun Director Mark 63. Note that the director is of the pedestal type, with a tracking head which the tracker moves in train and elevation by means of handle-bars.

FIGURE 16
GUN DIRECTOR MARK 63

The tracking head supports a lead computing gun sight. The tracker stands to look through the gun sight. Three other operators and a control officer complete the crew. Two operators handle the radar and search equipment provided with the director, and the third controls the inputs to the lead computing sight. To the credit of the persons responsible for the development of this type of director, it should be said that, in general, operation is very simple. No serious operating problems are met so long as the tracker can assume a normal stance while tracking, and so long as dials and controls on the rest of the equipment can be used in a normal. comfortable way.

Design problems arising from a failure to design unit parts in relation to the entire system.

Several examples of design problems which resulted when engineers who were given the job of planning unit parts were not familiar with the relation of those parts to the rest of the director system can be given with reference to the Gun Director Mark 52. Figure 17 shows a sketch of this director. Note that the engineering problem of properly balancing and counterweighing the tracking head was solved by putting the director input control panel at a low position at the side of the director. But the control panel was planned as a vertical panel and in this low location it could only be operated when the operator squatted next to the director or got on his knees. Unfortunately a relocation or a tilting of the panel was impossible in view of production schedules. The only satisfactory solution to the problem was to raise the director on a block so that the man operating the controls on the control panel would stand on a level some 20 inches lower than a specially built platform for the tracker. This arrangement is shown in Figure 18. An additional advantage of the arrangement was that it was possible now to make the platform for the tracker adjustable in height so that each tracker could look through the gun sight comfortably.

Designing a handwheel so that it turns in the same direction as the dial or needle which it controls is desirable because such handwheel turning fits in with the operator's normal reaction tendencies. Although such handwheel design is the rule, an exception was found in the early design of the Gun Director Mark 52. On the radar associated with this director, the range control handle is not geared directly into the radar, but is geared through a part of the fuze computer. Because of the way that the fuze computer was built, its intermediate gears produced a clockwise turning of the radar range needle when the handwheel was turned counterclockwise. It was not difficult to add another gear in the computer to reverse the motion of the handwheel shaft, but it is clear that this and the previously mentioned design problem (like others which could be enumerated) would never have arisen had the designers of the unit parts of the

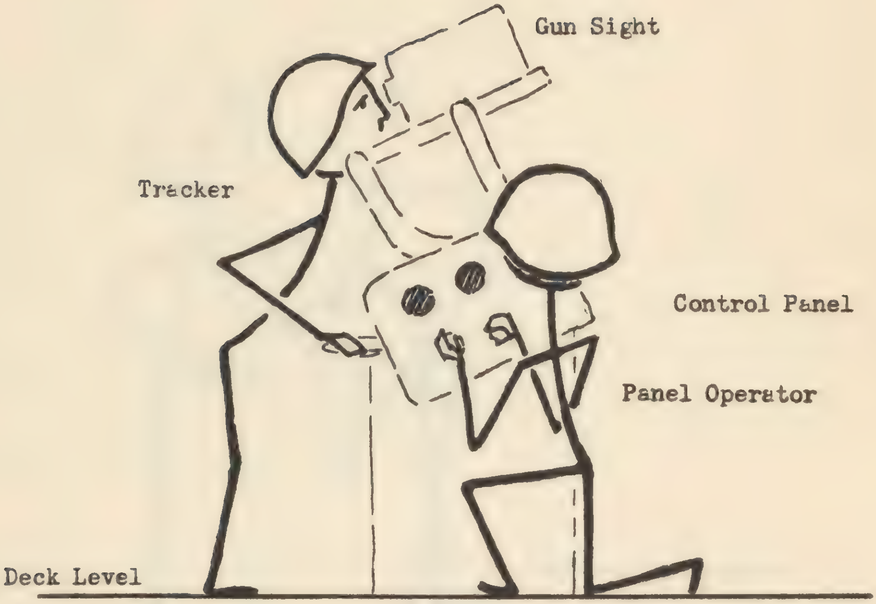

FIGURE 17

GUN DIRECTOR MARK 52 - ORIGINAL DESIGN

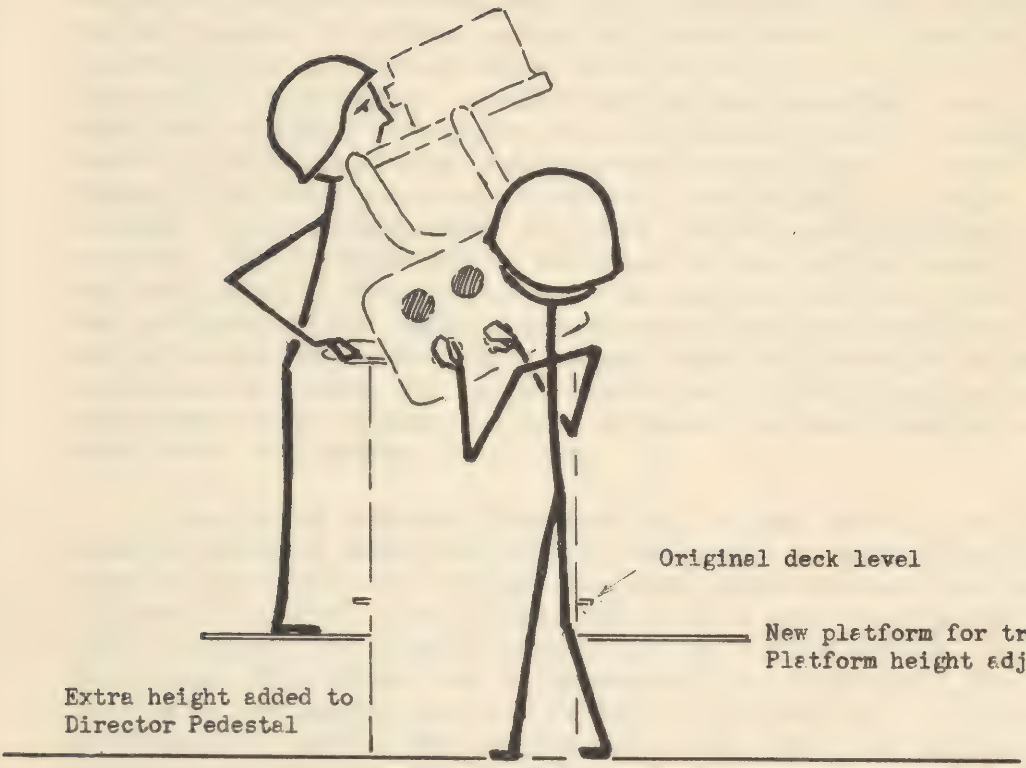

FIGURE 18

GUN DIRECTOR MARK 52 - MODIFIED DESIGN

system been completely familiar with the operating job required at each unit and with the intended physical relation of that unit to the next.

Design for training.

A design problem which bears on training as well as operation is met in the Gun Director Mark 57. The Mark 57 is a director which may be tracked by either optical or radar means. A picture of the tracking head and the tracking units of this director is shown in Figure 19. A telescope is used for optical tracking, and a separate unit with eyepiece and radar scope is used for radar tracking. The operator must shift from one eyepiece to the other in order to change from radar tracking to optical, or optical to radar. Let us suppose that a target which is being tracked optically moves behind a cloud. The tracker shifts his head to the left in order to use his left eye for radar tracking. He must cup his eye properly in the eyeguard on the radar scope eyepiece and look down at a small angle to see the scope. Once he has begun to track the radar dot, he can not see when the target breaks out of the cloud and can not know when he may resume the more accurate optical tracking unless some other crew member tells him.

A preferred tracking presentation is that used in the Gun Director Mark 63 where the optical and radar presentations are combined in one field of view and are seen simultaneously by one eye (Figure 20). With clear skies, the tracker always sees the gun sight reticle, the visible target and the radar tracking dot at the same time. To improve the brightness of the radar dot, the tracker may use a low density neutral filter to dim the sky. If the target goes behind a cloud, the tracker keeps the radar dot in the reticle circle until the target reappears. He does not have to shift his head at all. He carries on with no interruption in his task and is able to return to optical tracking as soon as the target returns to view.

But this combined telescope arrangement used in the Gun Director Mark 63 has other advantages too. It facilitates the task of checking the alignment of the radar and optical systems by reducing this check to a one-man job. Further, and most important, it simplifies the job of training men to track by radar. Because the radar image jiggles, the tracker must be instructed to track the "center of motion" of the dot and to track smoothly. If he can see what the real target is doing during practice trials when he is trying to track the radar dot, and can see how the radar dot moves about when he is holding the optical line of sight right on the target, he understands the radar tracking problem in short order.

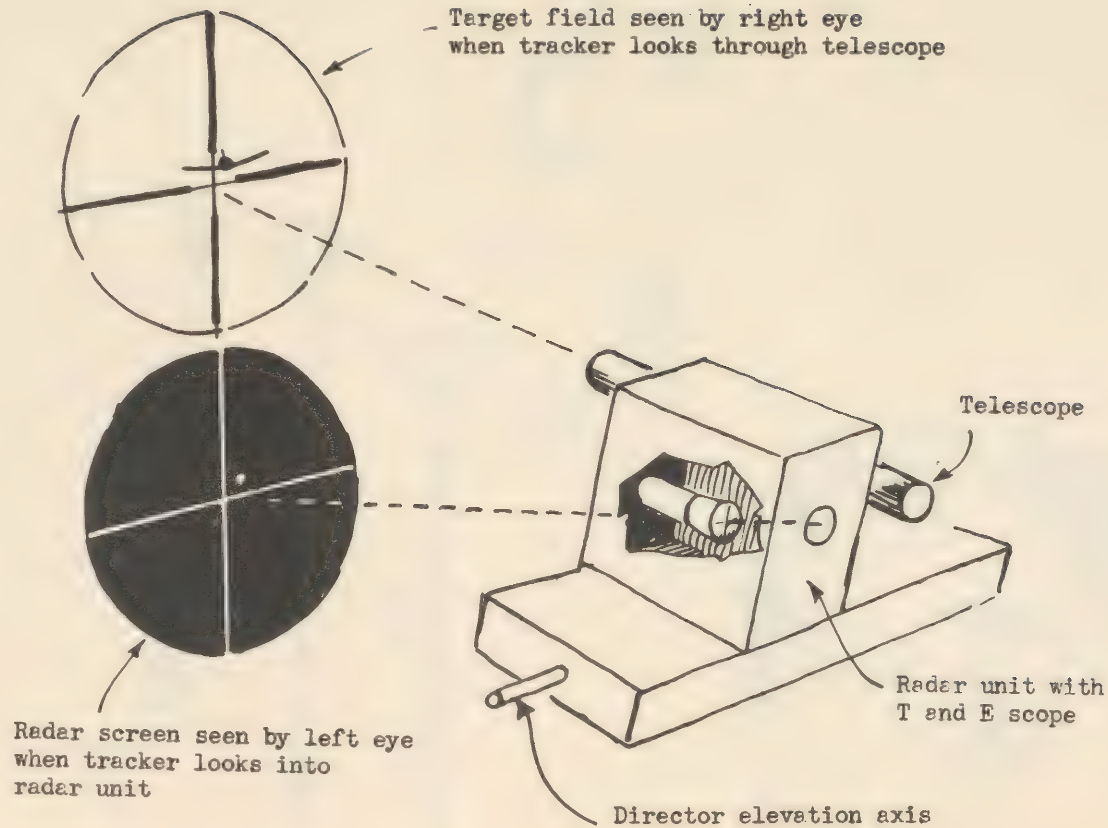

FIGURE 19. GUN DIRECTOR MARK 57 - TRACKING PRESENTATION

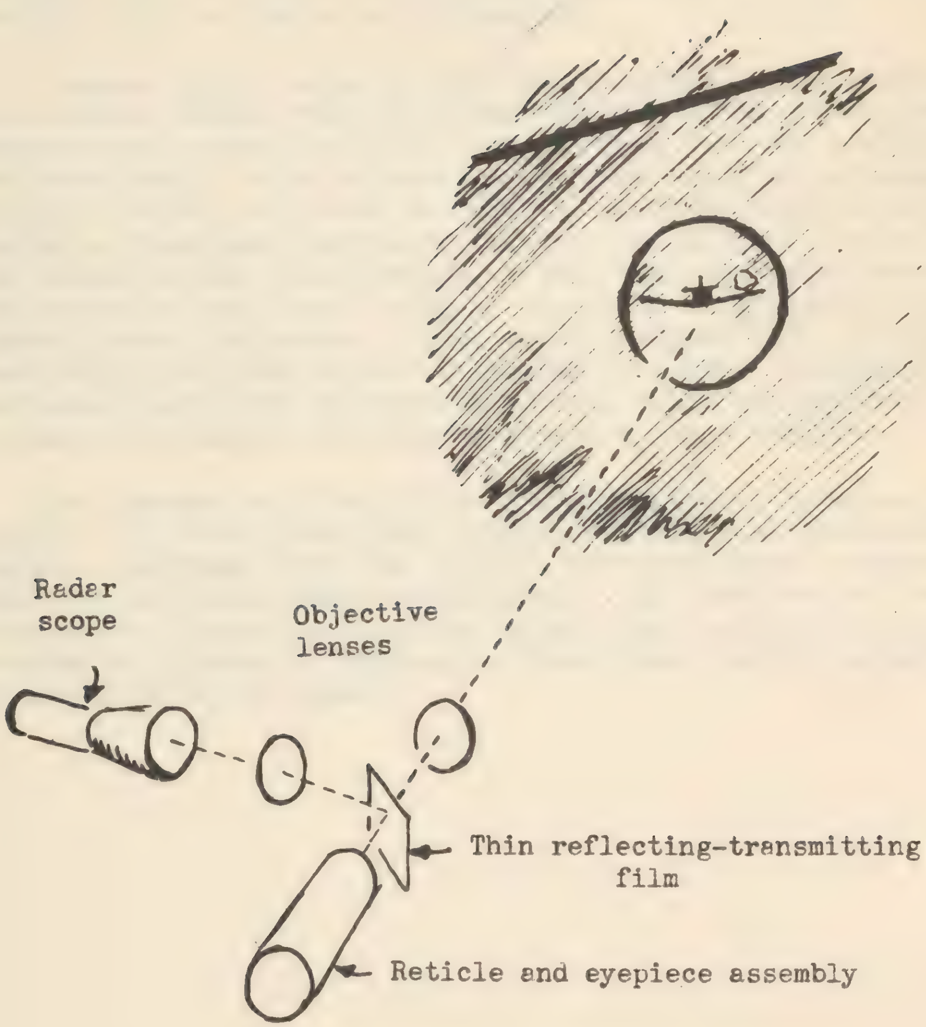

FIGURE 20. GUN DIRECTOR MARK 63 -
TRACKING PRESENTATION

Another case of "design for training" in connection with Navy fire control equipment relates to the development and use of check sights. For the past year and one-half there has been much interest in the construction of a check sight for use with the lead computing Gun Sight Mark 15. That check sight is still not in production. The longer it is delayed, the longer completely effective tracking training with the Gun sight is delayed.

Because of the value of check sight equipment for training purposes (amply demonstrated by Project SOS-6) as well as for use in alignment and firing tests, it seems obvious that the best plan for the future would be to require that a check sight be included as an integral part of every new gun sight or director which is designed. Putting an auxiliary checking scope into the optical system during its initial design should rarely be difficult and would save all the time which is later lost trying to attach or append check sights to already issued gun sights. Instruments designed with self-contained check sights or other assessing systems will make training efficient. Instruments which can be built to include their own synthetic training systems will simplify the task of training still further.

Our discussion of Navy fire control equipment has borne on two points: (1) Good operational design requires that equipment designers understand fully the physical and operational relations between the unit parts they are planning. (2) Good design for training requires that attention be given to training features which may be included in a piece of equipment without impairing its primary use for fire control in combat.

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